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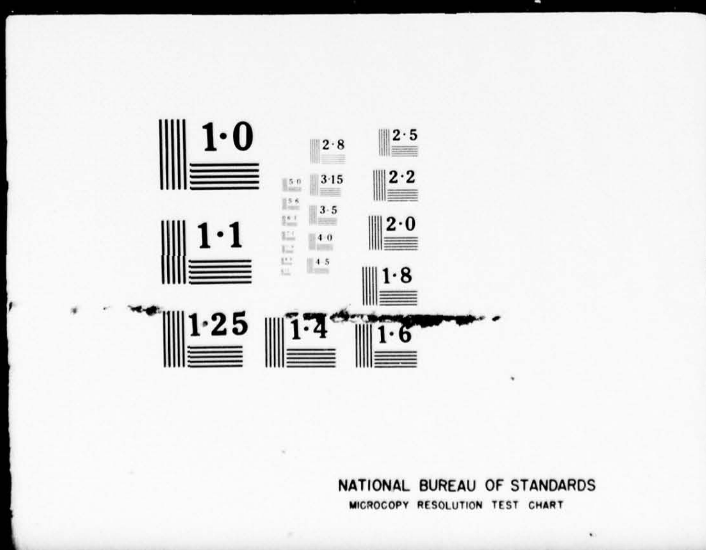

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UNITED STATES AIR FORCE

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Wright-Patterson Air Force Base, Ohio

AN IDENTIFICATION AND CHARACTERIZATION OF COST MODELS/TECHNIQUES USED BY THE AIR FORCE LOGISTICS COMMAND TO ESTIMATE JET ENGINE OPERATION AND SUPPORT COSTS

George H. Davidson, Captain, USAF
Raymond E. Griffiths, Captain, USAF

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The Life Cycle Cost (LCC) for jet engines includes the cost of design and development, test and evaluation, production, operation and support, and where applicable, disposal. Although only a small portion of the total LCC is incurred prior to production, the decisions made up to that point determine most of the total engine LCC. It is during this early design phase that there is insufficient operational information on the new engine to permit prediction of costs incurred during the operation and support phase of LCC. Estimation of LCC is further hindered by the absence of knowledge about techniques which could be used during engine design. This research involved a systematic investigation of the models and techniques used by the Air Force Logistics Command to estimate jet engine operation and support cost. These models and techniques are used in the areas of requirements determination for recoverable spares, engine overhaul, and total annual support-cost estimates for recoverable items. They are characterized to allow a determination as to their applicability for use during engine design.

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AN IDENTIFICATION AND CHARACTERIZATION OF COST MODELS/ TECHNIQUES USED BY AIR FORCE LOGISTICS COMMAND TO ESTIMATE JET ENGINE OPERATION AND SUPPORT COST

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

Procurement Major

By

George H. Davidson, BS
Captain, USAF

Raymond E. Griffiths, BBA
Captain, USAF

June 1977

This thesis, written by

Captain George H. Davidson

and

Captain Raymond E. Griffiths

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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DATE: 15 June 1977

Martin D. Martin
COMMITTEE CHAIRMAN

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LIST OF ABBREVIATIONS

ABLE	Acquisition Based on Logistics Effects
AFAPL	Air Force Aero Propulsion Laboratory
AFLC	Air Force Logistics Command
ALC	Air Logistics Center
ARI	actuarial removal interval
ATC	Air Training Command
BLSS	Base Level Self Sufficiency
CER	cost estimating relationships
COSPERANK	Cost and Performance Ranking Model
CREATE	Computational Resources for Engineering and Simulation, Training and Education
CSIS	Central Secondary Item Stratification
DI	dependability index
D/M	Directorate of Maintenance
DMS,AFIF	Depot Maintenance Service, Air Force Industrial Fund
DPSH	direct product standard hour
DSARC	Defense System Acquisition Review Council
EM	Engine Manager
EOQ	economic order quantity
ERRC	expendability, recoverability, repairability cost
ES	Equipment Specialist
FLU	first line unit

FMS	foreign military sales
ICA	Independent Cost Analysis Division
IM	Item Manager
JEIM	Jet Engine Intermediate Maintenance
LCC	life cycle cost
LOP	Directorate of Propulsion
LOR	Directorate of Material Requirements
LSC	Logistics Support Cost model
MAJ	Directorate of Industrial Fund Management
MOT	maximum operating time
MTBD	mean time between demand
NRTS	not reparable this station
NSN	National Stock Number
NT	normal thrust
OCBB	Operating Cost Based Budget
RCC	Resource Control Center
RTS	repaired this station
SFC	specific fuel consumption
SRU	shop replaceable units
TMS	type/model/series
USP	unit sales price
WRM	War Readiness Materials
WRSK	War Readiness Spares Kit

LIST OF AFLC SYSTEMS

D024	Propulsion Unit Logistics System
D024F	Actuarial Computations (Historical)
D024K	Actuarial Forecasts
D040	Recoverable Consumption Item Requirements System
D032	Item Management Stock Control and Distribution System
D033	AFLC Retail Stock Control and Distribution/ Control Materiel Locator System
D034A	Special Support Manager Stock Control and Distribution System
D041	War Readiness Materiel Requirements and Spares Support Lists
D062	Requirements Procedures for Economic Order Quantity (EOQ) Items
D075	Nonrecoverable Central Secondary Item Stratification (CSIS) Computational System
D104	Worldwide Stock Balance and Consumption Report Consolidation System
D143B	ALC Edit, Index, and Routing Subsystem
D143K	Intransit Control
G004C	Workload Programming, Planning and Control System
G019C	MISTR Requirements, Scheduling, and Analysis System
D033J	Past Program Data
G035A	Depot Maintenance Budget and Maintenance Cost System
G072A	Depot Maintenance Production Cost System

G072C	Depot Maintenance Program and Long Range Planning
G072D	Contract Depot-Level Maintenance Production and Cost System
H051	International Logistics Program Centralized Accounting and Reporting System
J005B	Standard Price Review Subsystem
J041	Management and Control of Due-In Assets
K004	Development of Program Data for Input to Consumption Item Requirements Computation
K008	USAF Programmed Aerospace Vehicles and Flying Hours by TMS

CHAPTER I

INTRODUCTION

Problem Statement

In April 1976, the Office of Management and Budget (OMB) issued circular number A-109 which established a need on the part of each agency to:

> Estimate life cycle cost during system design, concept evaluation and selection to ensure appropriate tradeoffs among investment costs, ownership costs, schedule and performance [59:5].

As developmental manager of propulsion technology programs, the Air Force Aero Propulsion Laboratory (AFAPL) has the responsibility for estimating the life cycle cost of Air Force turbojet engines during the design phase (27). However, the AFAPL has encountered problems in: (1) identifying Air Force Logistics Command (AFLC) data inputs and models/techniques which estimate operation and support costs, and (2) determining which of these models/techniques, if any, can be used in the design phase (27).

Justification

Life Cycle Cost (LCC) has been emphasized as a decision criterion throughout the acquisition process for major systems (59:1-5). To meet this criterion, costs are predicted for the various phases of the system's life (25:3). These phases are defined as conceptual, validation,

full scale development, production, operation, and disposition (25:3) (Figure 1). Since 95 percent of the cost drivers for life cycle cost, as related to jet engines, will be defined by the end of the full scale development phase (54:98), valid cost estimates must be provided during the conceptual, validation and full scale development phases to ensure appropriate decisions (54:98).

The AFAPL has used models such as Acquisition Based on Logistics Effects (ABLE), the Logistics Support Cost (LSC) model, the Rand model, and cost planning factors extracted from AFR 173-2 to estimate portions of jet engine LCC (2). However, as pointed out in the report of the 1976 DOD Procurement Management Review of Aircraft Gas Turbine Engine Acquisition and Logistic Support, the Air Force presently does not have the means to estimate total LCC (54:43). To overcome this problem, the AFAPL has sponsored several research efforts through the Air Force Institute of Technology to develop or identify models which could be used during jet engine design to estimate total LCC.

A research effort by Dover and Oswald developed a bibliographical review of LCC literature which provided a basis for this AFAPL sponsored research (7). With this background, a taxonomy of cost estimating characteristics was developed by the research team of Nelson and Smith (26:61-3). During the same time frame, the team of Yanke and Mullineaux developed a cost estimating methodology

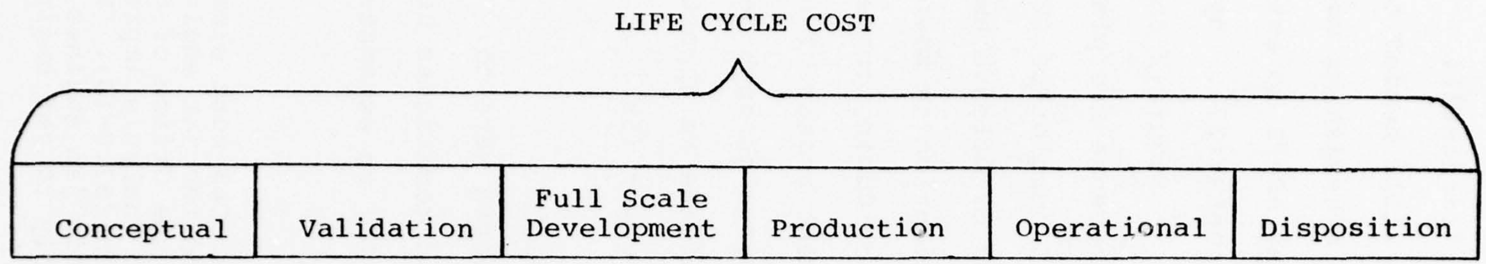

Figure 1

Jet Engine Life Cycle Cost

which could be used early in the acquisition process to predict jet engine production costs (25:51-68).

One area in which research still needed to be accomplished was the identification of existing models or techniques which could be used by the AFAPL to estimate jet engine operation and support (O&S) costs (27). Operation and support cost elements are shown in Figure 2 and defined in Appendix A.[1] The Department of Defense has placed special emphasis on controlling the O&S portion of LCC (58:1-2). In a recent directive, the Secretary of Defense expressed concern that ". . . insufficient attention is being paid to controlling eventual system O&S costs during conceptual, validation, and full scale development phases of new systems [58:1]." Reduction of these costs through decisions based on realistic cost estimates offers an opportunity for increasing real DOD purchasing power (58:1).

Research Objectives

The objectives of this research were to:

1. Identify cost models and techniques used by the Air Force Logistics Command (AFLC) to estimate jet engine operation and support costs.

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[1]During a literature review, O&S cost elements could not be specifically identified for jet engines. The elements developed for aircraft by the Office of the Assistant Secretary of Defense Cost Analysis Improvement Group were adapted for this research (57:8-10). When used, their application is solely for jet engines, e.g., replenishment spares only apply to jet engines.

COST ELEMENT STRUCTURE

Squadron Operations
- Combat Command Staff Manpower
- Aircrew Manpower
- Base Aircraft Maintenance Manpower
- Base Munitions Manpower
- Aircraft Security Manpower
- Aviation POL
- Base Aircraft Maintenance Material
- Miscellaneous Personnel Support

Base Operating Support
- Base Services Manpower
- Miscellaneous Personnel Support

Logistics Support
- Depot Maintenance Manpower and Materiel
- Supply Depot Manpower and Materiel
- Second Destination Transportation

Personnel Support
- Recruit/Technical Training Manpower
- Undergraduate Pilot/Navigator Training
- Medical Manpower
- Medical Materiel
- Permanent Change of Station (PCS)
- Miscellaneous Personnel Support

Recurring Investment
- Replenishment Spares
- Recurring Modifications
- Common Aircraft Ground Equipment (AGE)
- Training Munitions
- Training Missiles

Figure 2

Operating and Support Cost Elements (57:9)

2. Characterize these models/techniques to enable the AFAPL to determine if the models/techniques could be used during the design phase.

Research Question

What cost estimating techniques and/or models are used by AFLC to estimate jet engine operation and support costs?

CHAPTER II

BACKGROUND

Introduction

Major General H. H. Arnold supplied the impetus to launch the Air Force into the jet engine era. The first jet engine was the Whittle acquired from Great Britain (54:11). With a thrust to weight ratio of only 1.4 to 1.0, it was small compared to today's engines which have ratios of 8.1 to 1.0 (54:11-7). This great breakthrough in thrust is a result of tremendous achievements in jet engine technology (54:12-4).

This evolution of technology has not been without problems. Present-day engines, as did early engines, suffer from problems with lubrication, compressor surge, heat dissipation, high fuel consumption and rotation speeds (54:11).

Engines today also operate in a much more hostile environment. Internal operating temperatures often exceed the breaking point for the temperature strength curves of the metals used in the engines (54:11). This hostile internal environment is complemented by an equally hostile external environment of high altitudes, extreme temperatures, and severe vibrations (54:31). With all these

factors changing constantly, the engine must continue to perform (54:31).

Improved materials and cooling systems have enabled engines to develop much higher performance, but rarely can increases in performance and increases in engine life be achieved simultaneously (54:15). Past procurement practices have emphasized the former to the detriment of the latter resulting in most engines in the field designed with little thought to logistics support factors (10:7).

Consideration of logistics factors offers an excellent opportunity to reduce engine life cycle cost (54:52). The Air Force currently spends nearly $500 million annually for jet engine operation and support (54:7). One possible way to reduce these costs is application of the concepts of life cycle costing (5:1).

Life Cycle Costing

The Air Force life cycle costing program is designed to bring about reductions in system operating and sypport costs (18:15). This is accomplished primarily through prediction of O&S costs with subsequent consideration and analysis of the O&S implications of design alternatives (18:15). The specific objectives of life cycle costing are to: (1) determine economically feasible performance requirements, (2) provide design guidance to reduce O&S cost, (3) motivate contractors to reduce O&S cost

through improved designs, and (4) establish a basis for making tradeoff decisions between competing designs (14:8). These objectives are met through consideration of a "cost estimate" which has been defined as a ". . . judgment regarding the future cost of an object, commodity, or some service available for use [25:10]."

This judgment may be formulated using a variety of methods. The literature review revealed five generally accepted cost estimating techniques: engineering; rates, factors, and catalog prices; cost estimating relationships (CERs); specific analogies; and expert opinion (25:10). However, all estimating techniques/models can be placed into two categories--accounting and statistical (22; 25:10; 26:16).

Accounting Models

Accounting models compute cost by summing historical variables at relatively low levels of hardware breakdown and disassembly (6:55; 7:17-8). These models then project future costs by analogy with this historical summation (19:20). The accounting method assumes that detailed information, time, and money are available (25:10). When these assumptions are met, accounting models have the following advantages (25:11-2):

1. Accounting models are more accurate than statistical models because the availability of more information reduces uncertainty.

2. Since detailed data is available, the accounting models can be applied to subsystems or components facilitating sensitivity analysis and tradeoff decisions.

3. Direct extrapolation of O&S costs can be made with high reliability.

However, even when the underlying assumptions are met, accounting models have these disadvantages:

1. The relationship between future costs and historical data may change for many reasons (8:39). For example, engine parts are undergoing constant changes in design, material, and manufacturing processes. Because of the summation process, the accounting models may not accurately reflect the improved reliability of a given part or engine (10:6).

2. Subjective input information to cover unknown parameters may bias the reliability of the overall model (25:12).

3. The results from the accounting model may be so detailed that it hinders evaluation (25:12).

Accounting models are particularly useful in evaluating alternatives during or after the full scale development phase when data inputs are readily available (25:11). When accounting model assumptions cannot be met,

statistical models may provide a useful alternative for cost estimation.

Statistical Models

Statistical models reflect cost as a function of design or performance variables (8:31). For jet engines, the performance variable thrust is the single best parameter for deriving statistical models to estimate development and production costs (17:v). The assumptions underlying statistical models include: (1) similarity of physical and performance characteristics between an old and new system (25:13), (2) the existence of valid cost data bases for the old system (25:12), and (3) the application of sound statistical theory (25:14). The use of statistical models offers several advantages (25:14-5).

1. They can be used early in the life cycle of a system, e.g., the conceptual phase.

2. Subjective selection of input parameters is restricted which reduces user bias.

3. Statistical models provide a basis for construction of confidence intervals about predicted cost.

Statistical models also have certain disadvantages:

1. Cost relationships may change as a result of technological instability (17:7). Advancement in jet engine technology is a continuous process through the Component Improvement Program (CIP) (10:6). Changes made as a

result of the CIP may affect the relationship between performance variables and cost. This creates invalid cost estimates. Stable technology may affect this relationship as well. For example, commonality of jet engine components between a new and prior system may reduce development, production, and O&S costs considerably (17:7). Without periodic checks and adjustments to statistical models, cost information may not be reliable (19:14).

2. Statistical models are usually not applicable to radically new systems (25:14).

3. Statistical methods are conservatively inaccurate when applied to O&S costs (11:vi; 25:16). In 1967, maintenance support for the A7D was projected for 1973 using a statistical model (11:43-4). Actual maintenance costs in 1973 were 76 percent higher than the 1967 estimate (11:43-4). This conservative estimate was directly attributed to the use of a statistical model (11:44).

Either accounting or statistical models may be used to meet the objectives of life cycle costing. The choice of a particular model depends on the ability to comply with the assumptions previously outlined. Both methods are currently used to estimate jet engine O&S costs.

Cost Estimation--Jet Engines

Historically, LCC estimating tools for jet engines have been crude at best (54:43). The recent completion of

research by Yanke and Mullineaux (25), in which they developed a statistical model for predicting production costs, has provided the AFAPL with part of the LCC estimating capability needed (2). However, operation and support estimators such as ABLE, LSC, and Air Force Regulation 173-2 cost factors only provided a small portion of the O&S cost estimation requirement of the AFAPL (2). Consequently, research was needed to determine if other O&S models/ techniques existed which meet the AFAPL requirements.

CHAPTER III

RESEARCH METHODOLOGY

Overview

The need of the Air Force Aero Propulsion Laboratory to identify operation and support cost estimating models/techniques was described in Chapter I. To fulfill this need and answer the research question, many research methodologies were investigated to determine which would enhance this model/technique identification process. The literature search identified models and techniques on a continuum from simplistic, without written guidance, to complex with detailed written procedures. As a consequence of this diversity, the research methodology selected allowed the researchers the flexibility necessary to identify models/techniques regardless of complexity or extent of written instructions. The methodology chosen consisted of discussions with cost analysts and functional managers. This chapter provides a delimitation of the population as well as the data collection and model characterization methodologies.

Delimitation of the Population

A preliminary literature search was conducted of the Defense Logistics System Information Exchange and the

Defense Documentation Center. In addition, a review was made of reports, studies, and publications in the AFLC Technical Library, as well as the library of the Air Force Systems Command/Air Force Logistics Command Joint Commanders' Cost Analysis Improvement Group. The purpose of this literature search was to identify the population of interest. As depicted in Figure 3, the total population for jet engine O&S cost estimation is shown as an inverted triangle with increasing order of specificity. Because of time and resource constraints, the population for this research effort was the apex of this triangle, Air Force O&S cost estimation.

A search of Air Force publications was made to determine responsibility for estimating jet engine O&S costs. This search revealed two programs where cost estimation is performed--the budget system and the Cost Analysis Program. The first program is directed by Air Force Regulation 172-1 which describes the primary role of the budget system as estimating the costs of Air Force programs (55:2-1). This estimating responsibility is vested with functional managers at all levels (55:1-1), but estimates are consolidated at Air Force major command headquarters (55:2-2,2-4).

The second area of Air Force cost estimation is the Cost Analysis Program which provides estimates in

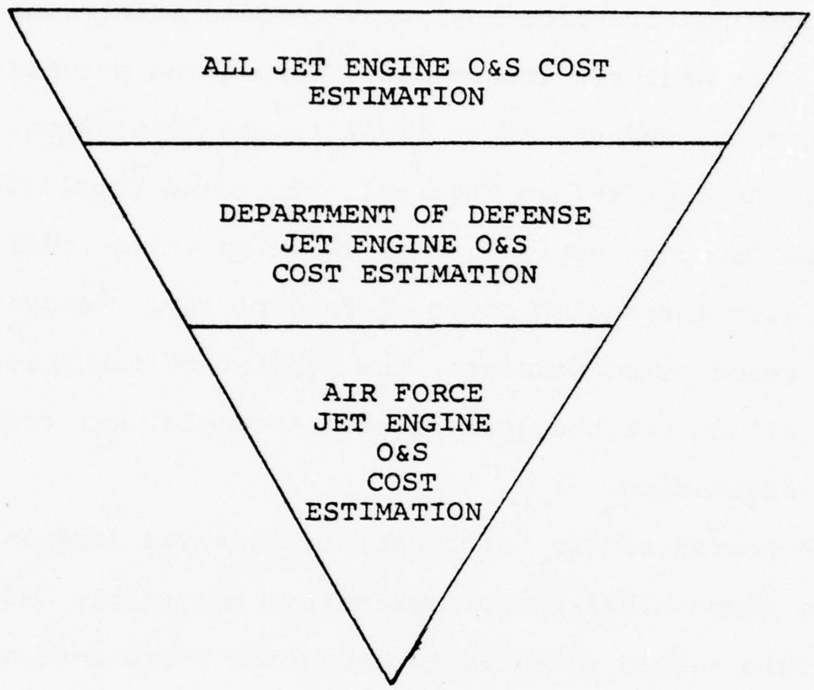

Figure 3

Jet Engine O&S Cost Estimation

support of major force programs (52:1).[2] Air Force Regulation 173-1 directs that each major command designate appropriate organizations within the comptroller to perform cost analysis functions (52:1-2). However, as in the budget system, primary responsibility for developing cost estimates remains with the organization having mission responsibility. Cost estimates developed under this program include cost factors for base operation and support, base maintenance, and other command activities (52:5-1).

As a result of the publication search, the population of interest for this research effort was jet engine O&S cost estimation performed or consolidated at the Air Force major command level. Within the major commands, three areas were investigated--budget, cost analysis, and engine management. Engine management was included because of its functional responsibilities.

Data Collection Methodology

In developing a data collection methodology, several requirements had to be met. First, the methodology had to permit flexibility in identification of the models. This was necessary because the literature search revealed that the models could range from highly sophisticated computer models to simplistic, manual-estimation techniques.

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[2]The Independent Cost Analysis functions outlined in AFR 173-11 are part of the Air Force Cost Analysis Program described above (53).

Second, the methodology had to guide the researchers so that sufficient information was gathered on each model/ technique to permit characterization; and finally, the methodology had to provide consistency in the data collection process. To meet these requirements, a data collection technique was selected, a data collection tool was developed, and a data collection plan was devised.

The data collection technique used was discussions with individuals identified during the pilot study in the field of cost estimation and jet engine management. These discussions were structured in the sense that specific objectives were addressed, but open-ended enough that they permitted the kind of investigative research necessary to determine what estimators exist.

The data collection tool used was a Discussion Objectives Guide (Appendix C). This discussion guide covered the following key areas:

1. Cost estimation process
2. Kinds of models and techniques
3. Model/Technique characteristics
4. Model/Technique uses

These key areas were further broken down into specific discussion objectives which were used by the researchers as a framework for model/technique identification and subsequent characterization. This guide also provided consistency in the data collection process.

The plan consisted of personal discussions with division chiefs at AFLC in the areas of budget, cost analysis, and engine management. These discussions were directed at identification of individuals within the respective functional areas who could provide specific information on cost estimating models/techniques. A pilot study was conducted which validated this plan.

Model Characterization

The accomplishment of the research objectives required a characterization which the AFAPL could use to determine which cost models/techniques are applicable to design tradeoff decisions. The characteristics defined in Figure 4 provide this information. These characteristics, as shown, were derived from two sources. Those identified with an asterisk were recommended by laboratory personnel (2). The remainder were derived from a list of LCC characteristics developed by Nelson and Smith (26:61-3). To meet the requirements for characterization for this research, some rewording and consolidation was accomplished.

The characteristics are explained in Figure 4, but one, decomposition, requires further amplification. This characteristic identifies models which have the capability of estimating costs of complete engines, sections, engine assemblies, or parts. Figure 5 provides definitions of four engine levels. For example, a model that predicts overall

I. General Model Characteristics

A. Type--the classification of the model, e.g., accounting, and/or statistical.

*B. Use--the kinds of estimates the model has provided and who uses those estimates, e.g., depot level cost estimates used for budgetary purposes.

C. Application Technique--the method by which the model is manipulated, e.g., computer, calculator, extrapolation.

*D. Decomposition--lowest level of component breakdown estimated within the model, e.g., one of the accounting equations determines turbine failure within a model which determines overall mean time between failure for the engine (see Figure 5 for engine levels).

II. Inputs

A. Data Identification--the kinds of data required to drive the model, e.g., flying hours.

B. Source--the location and method of obtaining input data, e.g., computerized data bank, periodic reports, etc.

C. Characteristics of Data--determination of whether data is an estimate itself, historical raw data, etc.

D. Format--the method by which the data is transformed for entry into the model.

III. Output

*A. Format--the form of the output, e.g., computer printout, required form, confidence interval.

*B. Time Frame--the period for which the estimate was made, e.g., one year, five years, life cycle.

*C. Parameter Estimated--the actual estimate provided by the model/technique.

Figure 4

Model Characteristics

Engine--complete engine.

Section--the immediate functional breakdown below the engine level (such as fan, compressor, combustor, etc.) which will be defined for each particular program (for modular engines, a section may equate to a module). The total of all sections will equal the whole engine. Final assembly completion, i.e., cost of not otherwise identified hardware, final assembly, green run, green teardown, reassembly and final test run.

Assembly--a number of parts joined together to perform a specific function and capable of disassembly.

Part--one piece, or two or more pieces joined together which are not normally subject to disassembly without destruction of designed use. (Examples: combustor basket, exhaust diffuser and fuel manifold.)

Figure 5

Engine Levels (47:Atch.3)

engine failure rate may not be sensitive to changes in part design because the failure rate is a function of flying hours and engine thrust. In this case, the level of sensitivity is the engine itself with no further decomposition. This information should assist the AFAPL in determining the appropriate uses of the models for design tradeoffs (2).

Revised Population and Research Methodology

Based on the pilot study (Appendix B), the population of interest and data collection plan were revised to include not only O&S cost estimation, but also parameters to which O&S cost might be associated, i.e., overhaul rates and repair cycles. Knowledge of how these parameters are estimated and costed should help the AFAPL to determine whether the same process or technique can be used during the design phase.

The pilot study also revealed that, in addition to AFLC, discussions with cost analysts at Air Training Command (ATC) and engine management personnel at Military Airlift Command (MAC) would identify O&S cost estimating models/techniques. Likewise, discussions with cost and functional managers at the San Antonio and Oklahoma City Air Logistic Centers (ALCs) would prove fruitful. Discussions were conducted from December 1976 through April 1977.

Discussions with Headquarters AFLC, ATC, and MAC personnel were planned to cover any estimation technique used, regardless of engine type/model/series (TMS). However, the Chief, Management Division at each of the ALCs indicated that tracking a specific type of engine would more expeditiously identify all cost estimating models/techniques used at the ALCs. Two engines, the F-100 and TF-33, were subsequently selected for tracking. The F-100 engine, managed by the San Antonio ALC, was selected because it would provide an identification and characterization of cost models used for an engine with modular construction. The TF-33, managed by the Oklahoma City ALC, was selected because it was considered a more stable engine.

Summary List of Assumptions

1. There are models currently in use which can be used during the design phase to estimate jet engine O&S cost.

2. The models/techniques used for the two selected types of engines provided a sample of models used at the Air Logistics Centers.

3. The O&S cost element structure identified in Figure 1 is applicable to jet engines.

4. The pilot study revealed the primary areas where O&S cost estimation is done for jet engines.

5. Model characterization provides the AFAPL sufficient information to determine model sensitivity to engine design changes.

Summary List of Limitations

1. Research was limited to cost estimators used in the budget, cost analysis, and engine management programs.

2. A list of O&S cost elements for jet engines could not be identified; as such, those developed for the entire aircraft had to be used.

CHAPTER IV

THE COST ESTIMATING ENVIRONMENT

Overview

This chapter will present the environment of the cost estimating models/techniques identified using the research methodology described in Chapter III. The researchers found that an understanding of the systems within which these models/techniques are used is essential for the AFAPL to evaluate the ability of a model or technique to estimate LCC or portions thereof. This chapter describes the AFLC, MAC, and ATC management systems which interface with the cost estimating process. The management process may produce cost itself or requirements that generate cost. Within this systems context, the individual models/techniques are then described in Chapter V using the model characteristics shown in Figure 4. Thus, with these model/technique characteristics; the perspective presented in this chapter; and the model/technique characterization presented in Chapter V; the reader will be in a better position to understand a given model or technique's function and applicability.

AFLC--The Air Logistics Centers

Two ALCs--Oklahoma City and San Antonio--are assigned Engine Managers (EMs) who provide worldwide

support for each type/model/series (TMS) engine (13; 37:3-6). TMS engine responsibilities are presented in Table 1. The Engine Managers are assigned to the Directorate of Materiel Management, Propulsion Management Division (MMP), Management Branch (MMPM) (13). In order to accomplish their worldwide support responsibilities, EMs use requirements and cost forecasts primarily obtained from Item Managers (IMs) assigned to the Requirements and Distribution Branch (MMPD), Propulsion Management Division. In turn, Item Managers are supported by the other branches within MMP. These branches and their support responsibilities are depicted in Figure 6. Although the EMs have a multitude of engine management responsibilities, the three planning and budgeting areas closely associated with O&S cost estimation are: replenishment of economic order quantity (EOQ) items, requirement computations for exchangeables, and depot overhaul maintenance cost and requirements forecasting.

TABLE 1

ENGINE MANAGEMENT RESPONSIBILITIES (24)

Oklahoma City		San Antonio	
J33	F101	J52	J85
J47	TF30	J60	F100
J57	TF33	J65	TF34
J71	TF41	J69	TF39
J79	JT3D	JT8D	
J75	JT9D		

DIRECTORATE OF MATERIEL MANAGEMENT

PROPULSION MANAGEMENT DIVISION

MANAGEMENT BRANCH (MMPM)	REQUIREMENTS AND DISTRIBUTION BRANCH (MMPD)	PRODUCTION BRANCH (MMPP)	ENGINEERING AND RELIABILITY BRANCH (MMPR)
Item Managers (IMs) who are responsible for worldwide support for a TMS engine, are assigned to the Management Branch.	This branch provides engine overhaul, exchangeables, and consumables requirements.	MMPP provides budget estimates for engine overhauls, exchangeables, and consumable items. They also function as the focal point for the DMS, AFIF.	Component Improvement Program (CIP) budget estimates are accomplished in MMPR.

Figure 6

The ALC Engine Management System

Besides these requirements and cost systems, a model, Cost and Performance Ranking (COSPERANK), was identified within the Engineering Services Division, Material Analysis Branch, Maintenance Data Section at the Oklahoma City ALC (29). This model is used to identify cost drivers for exchangeable items.

EOQ items are centrally procured, nonrecoverable, consumption type items identified by expendable, recoverable, reparable cost (ERRC) codes XB and XF3[3] (46:1-1). The engine front compressor synchronizing ring is a typical consumption item. Essentially, MMPD IMs compute requirements for EOQ items based on two years past demand using AFLC D062--Requirements Procedures for Economic Order Quantity (EOQ) (46:1-1). EOQ computations are updated at each ALC two times a month using the most current asset, demand, interchangeability and substitution listings, and stock list data (46:1-1). The D062 system also provides a forecast of quarterly demands for two years (12). Although the EOQ buy computation system is used primarily as an inventory control and replenishment system, it does generate input data for budgeting purposes by providing requirements and standard item cost to the D075, Nonrecoverable Central Secondary Item Stratification (CSIS) Computation System (41:i).

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[3]An ERRC Code is a pseudo code which places an item into either an expense or investment category.

Exchangeable requirements (repair and replenishment) are computed by MMPD using D041, Recoverable Consumption Item Requirements System (40:1-1). Exchangeables are identified by ERRC codes XD1 (Serialized Control and Reporting System-SCARS items), XD2, and XD3 ~~(32)~~.

The D041 system uses an operating base of projected aircraft flying hours multiplied by the number of engine per aircraft to arrive at projected engine hours. Factors based on demands and usages at various positions in the logistics cycle are then applied to the future operating program to project requirements. The system then computes stock level requirements, including War Readiness Material (WRM), for field and depot operations (40:1-1). Costs are established for exchangeable items, whether repair or replenishment, by National Stock Number (35:6-3). Requirements are then associated with cost to forecast operating budgets (30).

Depot level maintenance provides overhaul, conversion, modification and repair of engines (35:1-1). The Depot Maintenance Service, Air Force Industrial Fund (DMS,AFIF) is used to finance the costs of this maintenance, whether it is organic to the ALCs or contractual (40:1-1). The DMS,AFIF establishes a buyer-seller relationship between the Engine Managers and the Directorate of Maintenance (D/M) at each ALC (37:2). The Engine Manager "orders" depot maintenance from the D/M at a predetermined unit

sales price (USP) for each TMS engine. The DMS,AFIF then bills the customer based on work completed. Consequently, the depot overhaul portion of O&S costs are a function of engine requirements multiplied by the USP, both of which are forecasted for budgetary and management purposes.

The D024, Propulsion Unit Logistics System, is used by MMPD to compute depot maintenance engine requirements. Simply, the projected aircraft flying hours are multiplied by the number of engines per aircraft to arrive at projected engine hours. Overhaul removal intervals, which are computed by the D024 system, are then applied to the engine flying hours to compute a major portion of engine depot overhaul requirements (40:1-1). The DMS,AFIF system then attaches cost by applying a USP to each TMS engine.

DMS,AFIF USPs for engines are constructed so as to offset all costs expected to be incurred as an expense during the period of USP applicability (35:6-1). A USP is maintained for the current year, and a forecasted USP is developed for the budget year. The forecasted USP is applied to requirements for the budget year and four subsequent fiscal years for planning purposes (30). Two distinct systems are used to develop USPs. One system provides an organic USP for TMS engines, and the other provides a contract USP for those engines designated for contractual support.

For organic depot overhaul, the ALC Operating Cost Based Budget (OCBB) is used as a baseline for developing all USPs (35:6-1). Each Resource Control Center (RCC), or work center, within the Directorate of Maintenance projects expenses for the budget year. These expenses are converted to revenue rates for each RCC (40:9-3). The revenue rates are then used by the G072A, Depot Maintenance Production Cost System, to develop the USP. The USP is expected to cover the expenses shown in Table 2.

Military labor, investment, and exchange material are not included in the USP (35:6-1). However, the Uniform Cost Accounting System, currently being implemented within AFLC, will accumulate these costs (34).

Contract or interservice depot overhaul USPs are developed by the G072D, Contract Depot-Level Maintenance Production and Cost System. Future USPs are developed within the G072D system by using contractor agreed-to labor costs along with reports on contractor production and government furnished material. Since contract overhaul costs are a function of contractor or interservice supplied data, all future references to depot overhaul cost estimating will deal only with organic overhaul operations. Requirements generation for contract overhaul are computed the same as organic. A systems concept for depot overhaul requirements and cost estimating is shown in Figure 7.

TABLE 2

USP COVERED EXPENSES
(35:6-1)

D/M civilian labor and benefits
Expense material
Petroleum, oil and lubricants
Alteration of real property up to $75,000
Tools and equipment having a unit value of less than $1,000
Equipment rental
General and administrative costs
Non-creditable material returns
Custodial services
Other costs, such as temporary duty travel and per diem, transportation of household goods for permanent changes of station, training, tuition, printing, utilities, and contractual services

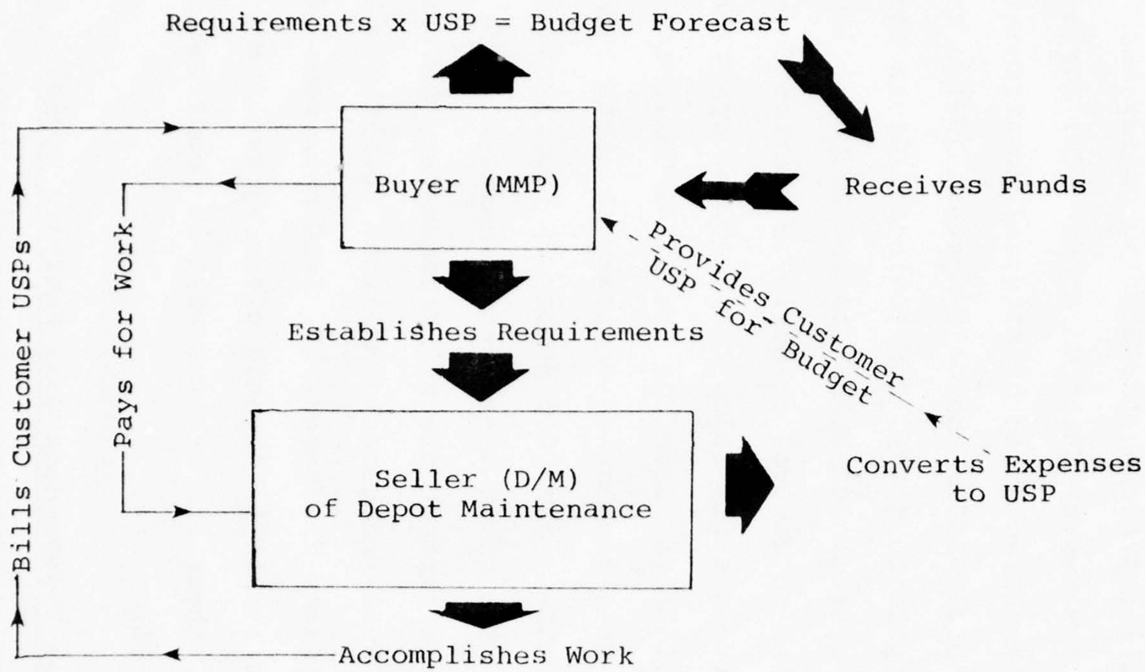

Figure 7

Model for Depot Requirements/Cost Estimating
(35:4)

Even though the ALCs are the focal point for engine support requirements and cost estimating, HQ. AFLC provides a management interface by formulating policy and direction. Under the Deputy Chief of Staff (DCS) Logistics Operations, the Directorate of Material Requirements (LOR) manages the D041, D062, and D075 systems (24). The Directorate of Propulsion (LOP), DCS Logistics Operations, controls the D024 system. COSPERANK is an Oklahoma City ALC development with no control or policy direction from HQ. AFLC because it is still being reviewed for approval. LOP and LOR maintain data bases for the D024, D041, and D062 systems, but they are not as complete as those maintained within the ALCs. The D075 system is only available at the ALCs (31). The G072A system and associated data bases are accessible through the DCS Maintenance, Directorate of Industrial Fund Management (MAJ), at HQ. AFLC. In addition to the systems discussed, HQ. AFLC uses some of the ALC systems as inputs to organic planning requirements. Where appropriate, these ALC systems will be described in the model characterizations.

AFLC--The Independent Cost Analysis Division

The Independent Cost Analysis Division (ICA), DCS Comptroller, Headquarters AFLC, formulates independent estimates of depot maintenance costs as an input to the Defense Systems Acquisition Review Council's production

decision (DSARC III) (61). These estimates are derived by using the Logistics Support Cost (LSC) model and/or cost estimating relationships (CERs) (4; 61).

The LSC model is the result of the evolution of another O&S cost model--ABLE (4). LSC model estimates are used to estimate the depot maintenance cost associated with a particular design (39:3; 61). Consequently, the basic model was not designed to accumulate absolute costs (39:3). However, the ICA feels that absolute cost for depot maintenance is accumulated using their techniques (4).

The basic LSC model consists of ten equations which represent the resources cost necessary to operate within the logistics environment. The first eight equations aggregate the cost of the total system. The other two equations represent costs unique to the propulation system the cost of fuel consumption and the cost of spare engines. However, the ICA only uses Equation 1--the cost of first line unit (FLU) spares--and Equation 3--off equipment maintenance--to estimate discriminate portions of depot maintenance costs (61). Equations 2, 4, and 5 through 10 are shown in Appendix G, and the associated variable definitions are presented in Appendix F.

CERs were devloped by the ICA to estimate depot repair costs for core engines and engine accessories. Traditionally, CERs for engine costs have used thrust, thrust

to weight, specific fuel consumption, and other performance parameters as independent variables. The ICA CERs are no exception. However, there are statistical implications that these "traditional" drivers of engine cost are not valid when used to estimate O&S costs (4). Consequently, there is current research underway to use physical, as well as performance parameters of engines, as the independent variables, i.e., number of fan blades, number of stages, material composition, etc. (4). Nevertheless, the current models being used are presented in Section B.

The Military Airlift Command Management Systems

Military Airlift Command, like all the operational commands, has a command engine manager who formulates policy, monitors base engine management, and assures that there is sufficient visibility given to engine problems (20). MAC, which is industrially funded, has developed a model which can be used to evaluate manpower needs, NRTS (not reparable this station) rates, and work station requirements. This simulation model aids in identifying bottlenecks in base-level maintenance (60). It is not used for cost estimation, and as such, was not reported in this research.

The Air Training Command Management System

Air Training Command (ATC) provides the formal technical training and field support training for engine

technicians. Investigation revealed that cost factors for formal technical training are published by ATC in AFR 173-2 by Air Force Specialty Code (AFSC) (9). These factors are derived by accumulating school operating costs for each AFSC. Field support training costs are not currently developed for engine support. Since Headquarters Air Training Command updates and publishes cost factors for formal training (56), no cost models were presented for ATC in this research.

Summary

This chapter presented the O&S cost estimating environment of the Air Force Logistics Command, Military Airlift Command, and Air Training Command. Within AFLC, the Item Managers and Engine Managers are key figures in the estimation of recoverable and consumable parts requirements. These estimates, when associated with a unit sales price or purchase price, provide budget forecasts. In addition to cost forecasting for parts, engine overhaul cost is estimated. Overhaul requirements when associated with a unit sales price also provide inputs to the budget process.

In addition to these requirements computation techniques, there were three models discussed which estimate cost directly--COSPERANK, the LSC model and CERs. COSPERANK calculates annual support cost for recoverable

items. The LSC model and the CERs are used by the Independent Cost Analysis Division of AFLC to formulate estimates on new systems.

Also discussed in this chapter were the cost estimating environments of MAC and ATC. However, as related to the objectives of this study, neither of these commands had relevant cost estimating models/techniques.

CHAPTER V

MODEL IDENTIFICATION AND CHARACTERIZATION

Introduction

A characterization of the models/techniques identified within AFLC which are used to estimate requirements and/or cost for jet engine operation and support is presented in this chapter. The chapter was constructed to allow independent evaluation of each model/technique within the framework it is used. Consequently, the characterization is presented in the following four sections: Section A: Model/Technique Characterization Format; Section B: The Models/Techniques Used by AFLC Engine Management; Section C: The Models/Techniques Used in the Independent Cost Analysis Program; and Section D: Summary. Section A provides the format used for the characterization of each model/technique. Using that background, the reader may extract an individual model/technique from Section B or C for independent evaluation. A summary section is then included to review the models/techniques discussed.

SECTION A: MODEL/TECHNIQUE CHARACTERIZATION FORMAT

The characterization format was designed to meet two objectives. First, each model/technique had to be

presented so that an independent evaluation could be made; and second, the model characteristics defined in Figure 4 had to be individually addressed. The first objective was accomplished by presenting an overview and summary of each model/technique within the environmental framework defined by Section B or C. The overview provides the model/technique in a systems perspective. The second objective was met by using Figure 4, Chapter III, as a format to discuss the individual model/technique characteristics. The summary reviews and integrates, in a narrative form, the characteristics presented for each model. This characterization format is summarized in Figure 8.

Model Identification
- Overview
- General Model/Technique Characteristics
  - A. Type
  - B. Use
  - C. Application Technique
  - D. Decomposition
- Inputs
  - A. Data Identification
  - B. Source
  - C. Characteristics of Data
  - D. Format
- Output
  - A. Format
  - B. Time Frame
  - C. Parameter Estimated
- Summary

Figure 8

Characterization Format for Each Model/Technique

SECTION B: THE MODELS/TECHNIQUES USED BY AFLC ENGINE MANAGEMENT

D024, Propulsion Unit Logistics System

Overview

The D024, Propulsion Unit Logistics System, is an AFLC information system which aids Engine Managers in decision making. Its stated objectives, as outlined in AFM 400-1, Vol. II (50:1-1), are to:

1. Maintain an accurate and timely engine inventory.
2. Reduce pipeline times.
3. Speed transportation.
4. Reduce overhaul times.
5. Extend field maintenance capabilities.
6. Streamline management techniques.

In addition, its actuarial forecasts may be used to measure actual increases in reliability due to engine modifications (51:3-1).

The ramifications of achieving these objectives can be more vividly seen by reference to the Engine Logistics Cycle depicted in Figure 9 along with the following description. It takes a given quantity of engines to meet installed requirements. There is also a quantity of engines required for the base maintenance repair cycle, the base-depot pipeline, and the depot repair cycle. A

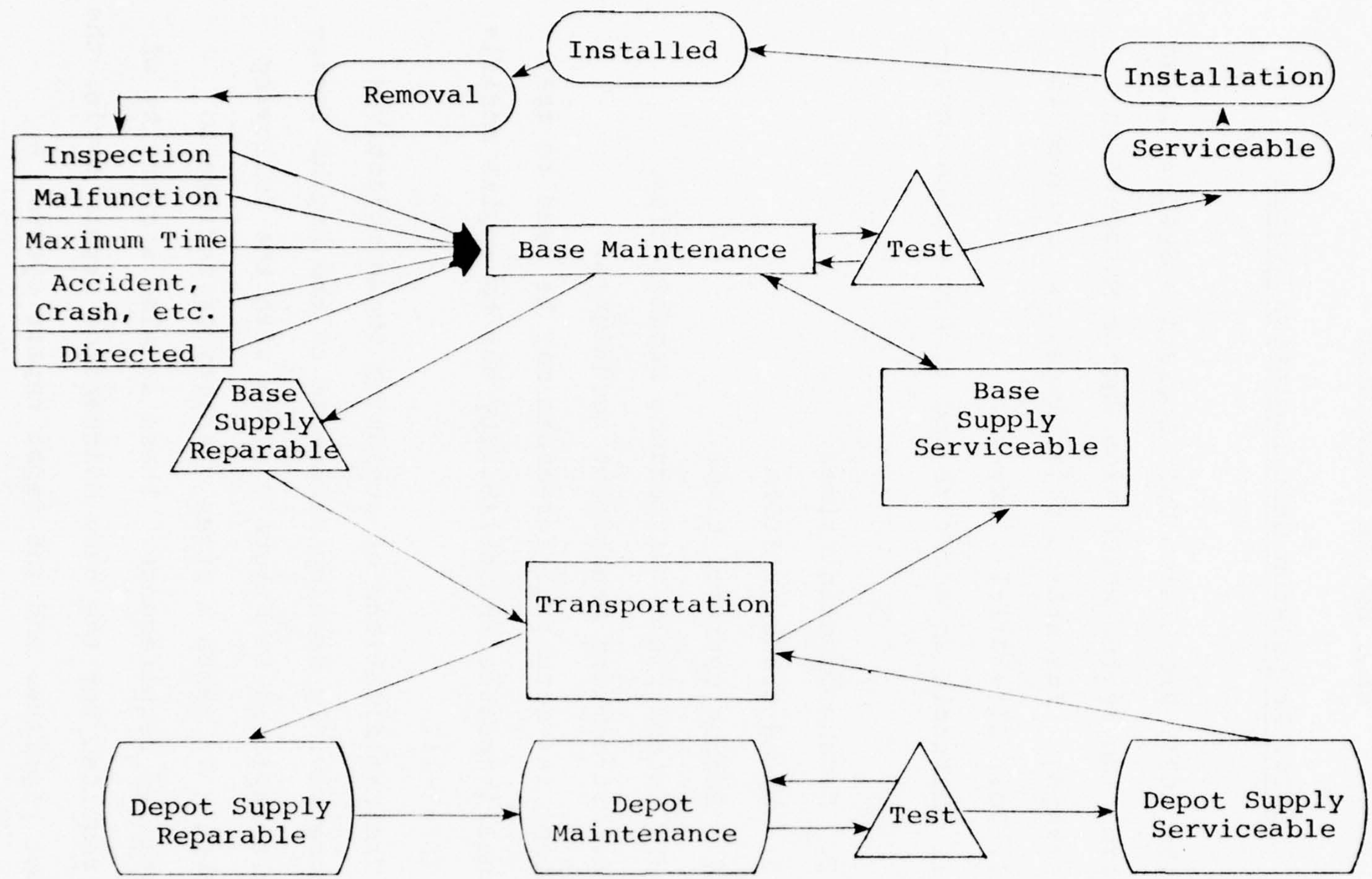

Figure 9

The Engine Logistics Cycle (28)

reduction in any of these three cycles will result in a decrease in the total number of engines required for that particular period.

The actuarial method is used to apply ". . . the principles and techniques of actuarial science (especially studies in life contingencies) to the field of Air Force Engine Management [51:1-1]." Data to support this method is collected through the Engine Status Reporting System. The inputs to this system are AF Form 1534, Engine Status Reports, and update reports submitted by field activities utilizing the Propulsion Unit Operating Time and Reconciliation Report, RCS:LOG-MMP (Q) 7101 (28). This data is reported to the Oklahoma City Air Logistics Center, Data Automation Division (50:1-1).

Of the subsystems of the D024 that exist (Table 3), the D024K is of interest to this research because of its forecasting of engine removal intervals. These removal intervals are drivers of overhaul requirements estimates (1). Consequently, they are instrumental in depot overhaul cost projections.

General Model/Technique Characteristics

A. Type--Accounting-Computer Simulation. Engine life is broken down into 20 hour intervals from zero to maximum operating time (MOT). The model simulates operating the engines during the time period under study to determine

TABLE 3

THE D024 SUBSYSTEMS

D024A	-	Data Collection
D024B	-	Inventory Control
D024C	-	Allocation & Distribution
D024D	-	Pipeline Analysis
D024F	-	Actuarial Computations (Historical)
D024I	-	Engine Configuration Management System (ECMS)
D024J	-	Financial Inventory Accounting
D024K	-	Actuarial Forecasts

an Actuarial Removal Interval for that type/model/series (TMS) engine (28). Actuarial Removal Interval (ARI) is ". . . the ratio of the projected engine operating hours per removal [42]."

B. Use--The D024K provides estimates of the Actuarial Removal Interval by quarter for the succeeding five fiscal years. The ARI is divided into three categories: overhaul removal interval (OHRI), base maintenance removal interval (BMRI) and combined (base and overhaul) maintenance removal interval (CMRI). OHRI and BMRI represent the worldwide fleet engine operating hours per overhaul and base maintenance removal respectively. CMRI represents all removals due to cause (42). OHRI and CMRI are further broken down to include those removals which

were required because the engine had reached its maximum operating time (MOT) (42).

The categories above are presented in tabular form by engine TMS on the computer output. These forecasted removal intervals are used by (42):

1. HQ. AFLC, to compute spare engine requirements.

2. Major commands, to establish engine stockage objectives.

3. Engine Inventory Managers, to compute overhaul requirements and retention quantities.

4. Military Assistance and Advisory Groups (MAAGS) and Missions, to compute spare engine and overhaul requirements.

C. Application Technique--The AFLC computer system is used to perform the D024K calculations.

D. Decomposition--The ARI is developed for engines as a whole and also for modules on those engines where the module concept applies, e.g., the F-100 engine (50:1-1).

Inputs

A. Data Identification--A depiction of the ARI development and required input data as shown in Figure 10.

1. Programmed Inventory--As an input, programmed inventory provides a forecast of engines on hand by quarter through 32 quarters (43:A2-24).

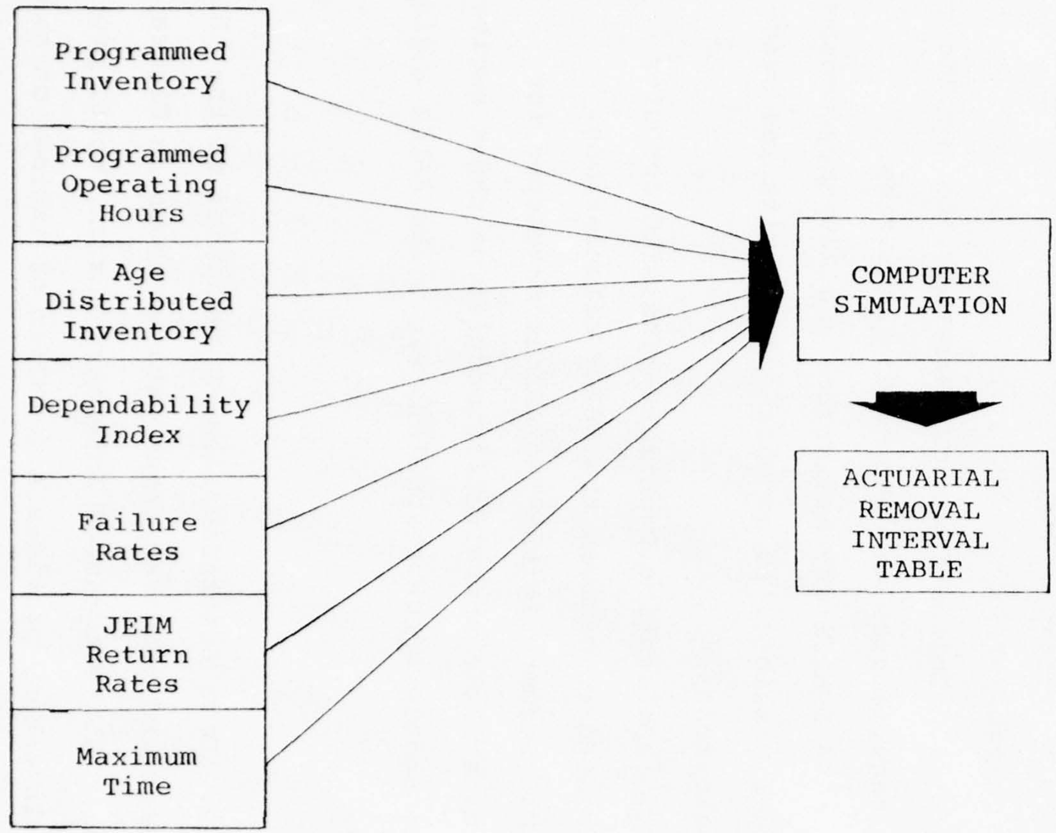

Figure 10

ARI Development (28)

2. Programmed Operation Hours--This input allocates programmed flying hours by TMS for engines.

3. Age Distributed Inventory--The age of the engine is zero when new and re-zeroed when it goes through overhaul (28). This input gives the current age of the engine as of the beginning of the quarter.

4. Dependability Index (DI)--A DI is an adjustment factor for future years which is based on present dependability and an expectation of future changes (51:4-3). It is a single factor used to adjust forecasts. The forecasts are based on the current official failure rates (28).

5. Failure Rates--Failure rates are computed for base maintenance, overhaul, and both combined. This is accomplished in the D024F subsystem. First, crude failure rates are calculated by dividing the number of engine removals by the number of exposures for a particular 20 hour age interval, i.e., 0-20, 20-40. . . . 1180-1200. An exposure is one engine operating completely through a particular age interval. If an engine fails within an age interval, a fractional exposure is calculated. For example, if an engine was removed after 50 hours of operation, it would be reported as one exposure in the 0-20 interval, one in the 20-40 age interval, and a .5 exposure in the 40-60 age interval. The summation of exposures for a particular TMS in a particular age interval is divided

into the removals to give crude failure rates. This is accomplished for all age intervals up to and including MOT (28).

Next, crude failure rates are statistically smoothed to arrive at a set of failure rates (51:5-2). The smoothed rates are further projected by using a least squares method (48:5-1). Finally, the projected rates are tested against the Official Failure Rate (OFR) for significant differences (51:5-2). Actuarial personnel at the ALCs are responsible for reviewing the official rates and recommending changes (51:4-2). For new and pre-production engines, a comparison engine with similar design and mission is used to develop actuarial factors (51:2-1).

6. Jet Engine Intermediate Maintenance (JEIM) Return Rate--The JEIM Return Rate is the percentage of total field usage removals which will be returned to service at the field level (28). Reason for removal codes are found in AFM 300-4 (42).

7. Maximum Time (MOT)--MOT is the management determined age in operating hours which defines the mandatory age to remove an engine for a major overhaul (28).

B. Source

1. Programmed Inventory--The K008 system (USAF Programmed Aerospace Vehicles and Flying Hours by TMS) provides the programmed engine inventory.

2. Programmed Operating Hours--Programmed operating hours are also obtained from the K008 system. The converted programmed flying hours and inventory by actuarial engine/aircraft combination is sent to Oklahoma City ALC (OCCSPS) for use in the D024K subsystem (51:5-4).

3. Age Distribution Inventory--This information is a computer output (D024F-102-N3) of the D024F subsystem (51:5-1).

4. Dependability Index--Responsibility for evaluating and recommending changes to the official DI rests with the engine actuaries at the ALC. Their recommendations are normally supported by analysis of actuarial products. They recommend changes to the Aerospace Engine Life (AEL) committee. The official rates are maintained in the OFR computer file at OCCSP (41:4-2 thru 4-4).

5. Failure Rates, JEIM Return Rates, and Maximum Operating Time--These inputs all have the same source as the dependability index--the OFR computer file.

C. Characteristics of Data

1. Programmed Inventory--Estimates of future engine inventories are provided by this input (28).

2. Programmed Operating Hours--This is an estimate based on the future flying hour program (28).

3. Age Distributed Inventory--Historical data provides the current age distributed (28).

4. Dependability Index--Because it is a mechanism which enables adjustment of anticipated future occurrences not reflected in the OFR, the DI is an estimate (28).

5. Failure Rates--These rates (OHRI, BMRI, and CMRI) are factors developed from historical data to estimate future failures (28).

6. JEIM Return Rate--JEIM return rates are estimates based on ". . . all available knowledge of future JEIM command capability, availability of tools and parts, and desired engine recycle time [51:4-4]." Thus, JEIM is a percentage estimate of the number of removals that will be repaired at the intermediate level.

7. Maximum Operating Time--MOT represents the estimated maximum time the engine can operate and still assure adequate reliability while providing maintenance economy (51:4-2).

D. Format--All seven inputs are fed to the simulation model from their respective data files. These data files are already established; consequently, no further transformation is required.

Output

A. Format--The D024K has many breakdowns of forecast outputs, but the D024KP06-K1 computer printout

provides the Official USAF Actuarial Removal Interval Tables.

B. Time Frame--The ARIs are projected for the current fiscal year plus twenty quarters (28).

C. Parameter Estimated--Actuarial Removal Intervals (ARI) are the relevant outputs of this system.

Summary of D024

The D024, Propulsion Unit Logistics System, is a simulation model. Its output is a projected actuarial removal interval which is obtained by simulating the operation of the engine through its projected operating program. The total removals are calculated by adding the engines removed and repaired by base maintenance to those removed and sent to the depot for overhaul. These total removals are called the combined removal interval. ARI computations are relevant to this study because they provide inputs to the Complete Engine Repair and Retention Requirements Computation.

Complete Engine Repair and Retention Requirements Computation

Overview

The D024K, as previously mentioned, computes an estimated actuarial removal interval by simulating engine operation for the projected operating program. The ARI does not, however, give the number of engines which need

to be repaired to support the engine logistics cycle. This information is developed by the Engine Repair and Retention Requirements Computation (33).

General Model/Technique Characteristics

A. Type--Using an accounting methodology, the individual requirements and projections of the engine logistics cycle are summarized. Pipeline times, stock levels, and repair cycles are aggregated and applied to the future operating program (33).

B. Use--A five year requirements computation is accomplished in the Requirements Branch at each ALC, and the products are reviewed by AFLC/LOI (1). By computing the total number of engines needed and the number requiring overhaul, depot overhaul workload planning can be accomplished (1). Also, the number of engines to be repaired is used by AFLC/LORER for budget preparation (15). In the budgetary process, the USP for the current and next fiscal year are provided by AFLC/MAJ (15). For the succeeding three years, the USP estimate is not changed in estimating engine overhaul costs. In summary, projected overhaul requirements by quarter are multiplied by the projected USP for a total of five years (15).

C. Application Technique--The current computation is done manually. Mr. Robert Short, of the Oklahoma City ALC, has developed a computer program which will

significantly reduce the manhours required for manual computation. This computer application is presently being considered for approval by HQ. AFLC (33).

D. Decomposition--The lowest level of component breakdown is the total engine level with the exception of those engines where the module concept applies (33). For modular engines, estimates are provided to the section level.

Inputs

A. Data Identification--

1. Peacetime Flying Hour/Force Structure Program--USAF Program Aerospace Vehicles and Flying Hours (PAX-XX). These PA documents provide the projected peacetime flying hours by aircraft for the next five years (33).

2. Wartime Flying Hour Program--USAF War Mobilization Plan (WMP-6). Projected wartime flying hours by aircraft are provided by this input (33).

3. Engine Planning Schedule and Engine Production Schedule--This information applies only to new engines entering the inventory and allows projection of future inventory position based on these schedules (33).

4. Actuarial Removal Interval Tables--ARI tables provide estimates, by quarter, of the interval between engine removal.

5. Pipeline Standards--Pipeline standards are broken into three major elements: automatic resupply and buildup time (ARBUT), base repair cycle, and depot overhaul cycle. The resupply and buildup time covers the following: the period that it takes the base to notify the depot that an engine has to be resupplied due to an overhaul requirement; base receipt of this resupplied engine; and buildup of the resupplied engine for installation on the aircraft. Base repair cycle is defined as the time that elapses, beginning with the removal of a reparable engine, and ending when it is ready for reinstallation (49:A-1). Depot overhaul cycle covers the removal time of the reparable engine, transportation time to the depot, and time to overhaul (49:A-2). The ARBUT, the base repair cycle, and the depot overhaul cycle, inclusive, provide an average number of days to accomplish the base/depot pipeline (49:7-1).

6. Safety Level Tables--These tables enable calculation of a safety level of engines to prevent stock-out at base level due to longer than normal pipeline times (49:A-1). The appropriate safety level table is chosen based on whether the engine is utilized for combat, combat support, or others (49:8-7).

7. Negotiated Base Stock Level--Base stock level is the quantity of engines required to fill the

ARBUT cycle, base maintenance cycle, and safety level requirement (49:A-2).

B. Source

1. Peacetime Flying Hour/Force Structure Program--This information can be obtained from the K008 system as described in the D024K model (classified information) (1).

2. Wartime Flying Hour Program--This information also can be obtained from the K008 system (classified information) (1).

3. The Engine Production Schedule and Engine Planning Schedule--This input is obtained from AFSC systems program offices (classified information) (33).

4. ARI Tables--These can be obtained from HQ. AFLC/LOP.

5. Pipeline Standards--These are published in AFM 400-1, Volume I.

6. Safety Level Tables--These also can be obtained from AFM 400-1, Volume I.

7. Negotiated Base Stock Level--The negotiated stock level objective is maintained at HQ. AFLC/MMP for in-production aircraft, APUs and aerodynamic missile engines. For other engines, the negotiated stock level objective is maintained at the ALC responsible for that engine. These stock level quantities are maintained on AF Form 811s (classified information) (49:8-5).

C. Characteristics of Data--

1. Peacetime Flying Hour/Force Structure Program--The PA input is an estimate or projection (33).

2. Wartime Flying Hour Program--This information is an estimate of aircraft flying hours in a wartime scenario (33).

3. Engine Planning Schedule and Engine Production Schedule--These schedules provide estimates of engine production quantities and dates for introduction into the Air Force inventory.

4. Actuarial Removal Interval Tables--These tables provide estimates of the interval between engine removal.

5. Pipeline Standards--Pipeline standards are estimates of the number of days required for the resupply and buildup, base repair cycle, and depot repair cycles. They are updated by the Executive Level Engine Logistics Planning Board when deviations warrant change (49:7-1,7-2).

6. Safety Level Tables--As an input, safety levels are based on estimates of the number of engines required when the pipeline is longer than normal (49:A-1).

7. The Negotiated Base Stock Level--A negotiated estimate is established for the number of engines required to fill the ARBUT, base maintenance cycle, and safety level requirement.

D. Format--All inputs, except the ARI tables, are required AFLC or ALC forms.

Output

A. Format--The format of the output is a required form--AFLC 538--for ALC computations (33). Consolidation from the ALCs is made of HQ. AFLC.

B. Time Frame--The estimate of overhaul and retention requirements is made for the current fiscal year and the succeeding four fiscal years (1).

C. Parameter Estimated--The Complete Engine Repair and Retention Requirements Computation estimates the number of engine overhauls based on the projected flying hour program (33).

Summary of Complete Engine Repair and Retention Requirements Computation

This computation calculates the actual number of engines required to support the engine logistics cycle for the current and next four fiscal years. These quantity forecasts can be matched with estimated engine repair cost to provide a five year forecast of engine overhaul cost. This technique is now manually calculated, but computer capability is in the approval process.

D041, Recoverable Consumption Item Requirements Computation System

Overview

The D041, Recoverable Consumption Item Requirements Computation System, ". . . is an AFLC system which accumulates or adjusts requirements data, such as maintenance factors, for the computation of requirements of recoverable consumption type items [44:1-1]." Commonly called exchangeables, these items are identified by ERRC codes XD1, XD2, and XD3. They are initially funded through investment appropriations as exchangeable spares (3). The requirements computation of the D041 identifies the need to buy, repair, terminate, or dispose of a recoverable item (3). Data for each item is aggregated by master stock number (44:5-2). The data necessary to drive the D041 computations is composed of biographical, historical, and usage factors (44:5-2,5-3).

Collection of data and computation of requirements is vividly presented in Figure 11. In determining actual numbers of items required, consideration must be given to the number of base-reparable generations for that item, the number that can be repaired at the base (repaired this station--RTS), the number condemned at the base level, the number sent to depot (not reparable this station--NRTS), reparable intransit time, depot condemnations, depot reparable generations, and depot item repair. This demand

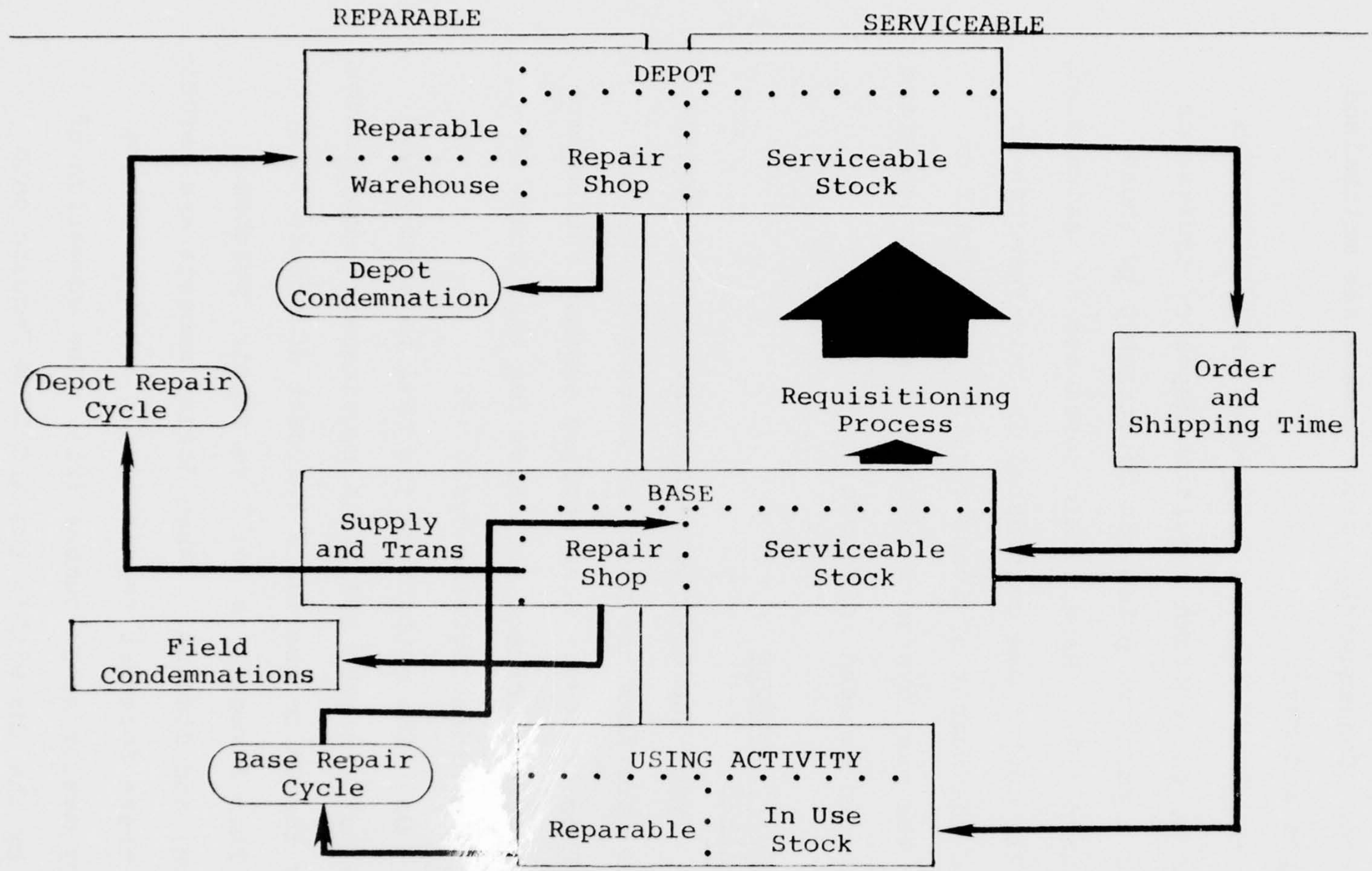

Figure 11

Exchangeable Logistics Cycle (3)

and supply relationship between the base and depot is not deterministic. Consequently, stock levels are maintained at both depot and base.

In terms of costs, a unit sales price (USP) can be attached to those items requiring depot or contractor repair, and a purchase price can be attached to those items procured (32). Base repair costs are not calculated. The D041.J21A output was considered in this research as it provided the number of items required for repair or overhaul. The many system interfaces required to generate this output can be seen in Figure 12.

General Model/Technique Characteristics

A. Type--The D041 is an accounting model which accumulates data from the past two years and computes factors. These factors, when applied against future programs, provide requirement estimates for that facet of the recoverable item logistic cycle (32).

B. Use--The outputs of the D041 have many uses. One of the outputs, the D041.J21A requirements computation, is used by the IM to provide a forecast of future item demands. This forecast is for item repair, purchase, termination, and disposal. When dollar amounts are associated with these forecast requirements, a budget can be computed by master stock number (21). The summation of forecasts by the IMs within the ALC D/MM Requirements

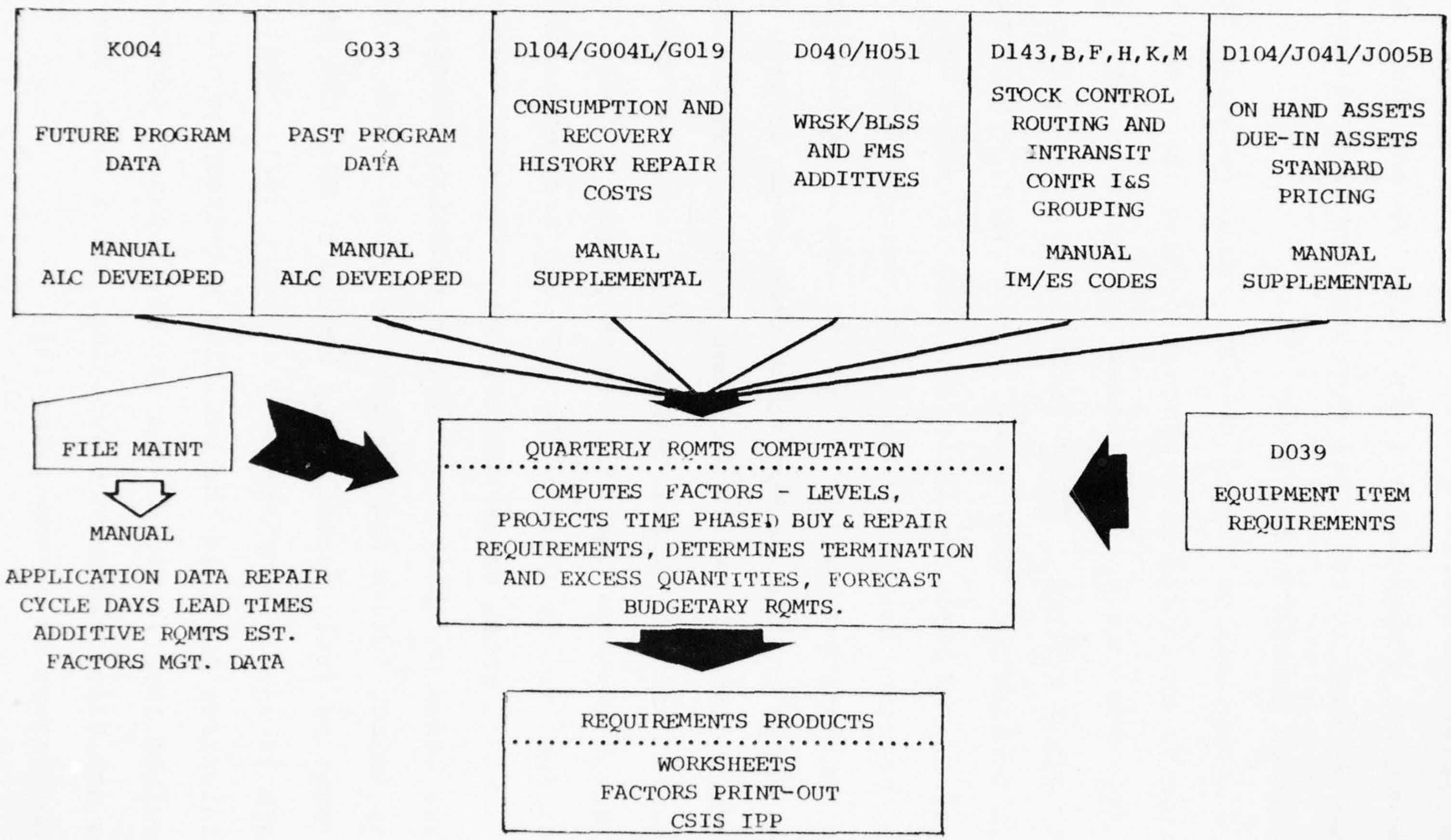

Figure 12

The D041 System (3)

Branch provides the operating budget needed to support requirements for exchangeable items (21). In addition, this system may be used to calculate requirements buy and repair for production management purposes (32).

C. Application Technique--The actual requirements computation is an interactive process between the computer and the IM. The computer calculates factors based on a 24-month moving average. These factors are organizational and field maintenance (OFM) total demand rates, OFM depot demand rates, OFM base repair rates, wearout rates, base processed percent, base condemnation percent, and depot overhaul condemnation percent (44:6-4). These factors are then applied to the future operating program to develop an initial requirement. The IM can then make adjustments to requirements based on this knowledge of future programs, special circumstances, and additive requirements (32). Equipment Specialists (ES) at the ALC, who are responsible for particular master stock numbers, may make adjustments in factors based on their knowledge of technical changes which may impact future demands for the item. These revised factors must be fully justified by the IM or ES. The factor update is one file maintenance activity (32). Another file maintenance input is the additive requirements which are described later. Factor changes and input of additives complete the file maintenance function, and a final computer computation is accomplished (32).

D. Decomposition--Forecasts of requirements are made down to the master stock number which can be identified with a national stock number (32). This falls within the assembly classification.

<u>Inputs</u>

A. Data Identification--A frame of reference for the inputs, processes, and outputs of the D041 system can be gained from Figure 12.

1. File Maintenance--File maintenance, as previously described, is performed by manual inputs of the IM with additional advice from the ES. It is a continuous update process for the IM. When he has more current information, such as changes to the unit price, procurement lead time, or repair cycle, he updates the computer. Also, the IM can manually input validated requirements, called additives, for such things as War Readiness Materials (WRM), mission support kits, special projects, etc. (44:1-29). These additives remain in the system for only one quarter's computation (44:1-29). This file maintenance activity is especially important for update after the initial requirements computation to insure accuracy of the final computation (32).

2. Future Program Data--The K004 inputs future programs for engine hours, overhauls, management of items subject to repair (MISTR), inventories, etc. (44:4-8,4-9).

3. Past Program Data--The G033J system provides past program data. HQ. AFLC prepares past program data monthly. This data is used by the ALC to manually develop the past program data for the three months preceding the quarterly computation. This new data is used to update the 24-month data base. Essentially, the oldest three months data is dropped when this new data is added (44:6, 4-7). The 24-month data is used to develop factors for requirements computation (32).

4. Consumption and Recovery History, and Repair Cost--The D104 system provides quarterly inputs on item usage for such things as base condemnations, base RTS, base NRTS, depot reparable generations, and depot condemnations (45:5-22). The G019 system inputs unit repair cost for the items (32). The G004L provides overhaul condemnations (32).

5. The War Readiness Spares Kits/Base Level Self Sufficiency (WRSK/BLSS)--These inputs comprise the additive requirements for War Readiness Materials (WRM). The foreign military sales (FMS) additives from the H051 system are in support of supply commitments with foreign governments. Both additives are entered into a fifteen-quarter, time-phased requirement during each computation cycle (44:15-19).

6. Stock Control, Routing and Intransit Control of Interchangeability and Substitutability

Grouping--Several inputs are provided by the D143 subsystems. These subsystems provide stock control data for management and file maintenance information on base order and shipping time (OS&T), and they also provide intransit control and the capability to identify part interchangeability and substitutability ranking. This allows for cross-referencing of the various items (32).

7. On Hand Assets, Due-in Assets, and Standard Pricing--The interface with the D104 system provides on-hand assets by identifying whether the item is serviceable or unserviceable with a breakdown on the item location, i.e., base, depot, contractor, WRM, etc. This information is provided in summary form (44:5-17). The J041 has a record of items due-in from reclamation, purchases, interdepartmental transfers, etc. (45:A2-2). The standard pricing for repair and purchase is maintained in the G019 system. The G019 is monitored and continuously updated through the J005B system ensuring accurate pricing rates (32).

8. Equipment Item Requirements--The D039 performs a file maintenance function which updates the future program by advancing the program-begin date for each quarterly requirements computation (44:4-2).

B. Source--

1. File Maintenance--File maintenance is an IM/ES determination based on knowledge of item and future program changes (32).

2. All of the remaining input data is accessible through the AFLC computer (45:A2-1).

C. Characteristics of Data--

1. File Maintenance--As stated earlier, judgment is used based on item knowledge.

2. Future Program Data--Future engine flying programs are estimates (44:4-8).

3. Past Program Data--Historical raw data is used as past program data (44:4-6).

4. Consumption and Recovery History and Repair Cost--The D104 and G004L provide historical raw data. The G019 provides estimates of unit repair cost.

5. WRSK/BLSS and FMS Additives--Both D040 and H051 provide estimates of future requirements (44:5-19).

6. Stock Control, Routine and Intransit Control of Interchangeability and Substitutability--Data from this system is historical.

7. On Hand Assets, Due-in Assets and Standard Pricing--Historical raw data is used from this input.

8. Equipment Item Requirements--As this is a file maintenance activity, no data is provided.

D. Format--All inputs, except file maintenance, are obtained from computer data bases. Specific information is abstracted from these data bases and is not transformed prior to entry into the D041. The file maintenance is not a data transformation but an input of changes to factors, changes in requirements, and other additives.

Output

A Format--The form of the output is a computer printout (32).

B. Time Frame--The factors developed for the computation are based on a two-year moving average; consequently, after the second forecast year, they remain constant. Operating programs to which these factors are applied cover 25 quarters plus a three year retention period (32).

C. Parameters Estimated--The estimates are for repair, buy, termination, and disposal for each item with an ERRC code XD1, XD2, and XD3.

Summary of D041

The D041 calculates requirements for exchangeable items identified by ERRC codes XD1, XD2, and XD3. These requirements are filled through repair, replacement, or reclamation. In calculating budgetary requests, a unit sales price is attached to those items to be repaired, and a purchase price attached to those items to be replaced.

The summation of these two calculations provides the cost to support that particular item. The exchangeables requirements forecast is provided for twenty-five quarters plus a retention period.

D062, Requirements Procedures for Economic Order Quantity (EOQ) Items

Overview

The purpose of the D062, Requirements Procedures for Economic Order Quantity (EOQ) Items, is to project future EOQ requirements so that necessary actions can be taken to insure that sufficient stocks are available to support system customers (31). Within this context, engine EOQ requirements for base and depot support are forecasted by IMs at the ALCs. The engine EOQ computations are designed to: accumulate engine EOQ demand data; compute depot safety stocks; determine buy, termination, and long supply quantities; provide a baseline for funds projections; and provide historical reports for management of the system (31). Most of these computation functions are related to inventory control and management; however, EOQ demand factors generated by the D062 system provide an input to the D075, Nonrecoverable Central Secondary Item Stratification (CSIS) Computation System. The D075 forecasts EOQ costs by quarter for two years by simulating the logistics system using D062 demand factors (31). These forecasts are used in the planning and

budgeting process (31). Even though the D075 system matches the cost to the requirement estimates for EOQ items, the D062 system provides most of the data inputs. Consequently, the D062 is presented as the major technique for deriving EOQ item costs. The D075 interface is presented under the "Parameter Estimated" section of the D062 characterization.

The D062 system provides EOQ requirements using two different computational methodologies. The Type B computation is based on as much as two years historical base and depot recurring demands, and defined Quantitative Requirements (QRs) (46:1-5). The recurring demands are based on depot and base requisitions processed by the Item Management Stock Control and Distribution System (AFLC D032/D034A computer systems) (46:3-1). Quantitative Requirements (QRs) are derived from a baseline other than recurring demands (46:1-2). QRs are usually computed to support WRM requirements, net increases in end item populations, or unprogrammed workloads (46:1-2). A Type B methodology, where past demands determine future requirements, is used for the majority of EOQ items, including almost all depot requirements (31). Type C computations are used when the EOQ requirements are not related to past demands, such as calendar time changes or short program life items (46:1-5). Type C computations are not considered in this research since operational program changes

which are not predictable, dictate these requirements. After EOQ requirements are projected under a Type B methodology, current EOQ unit prices are attached to provide a projection of EOQ costs (31).

General Model/Technique Characteristics

A. Type--The D062 system computes a "demand factor" based on accumulated historical data. Consequently, the D062 process was designed as an accounting technique which projects EOQ demands for inventory engines. New engine EOQ costs are normally projected by analogy with an existing engine (12; 31). When the new engine is an advance in technology (no analogy possible), contractor data is normally used to project EOQ requirements (12; 31).

B. Use--The D062 system is primarily used for inventory management. However, D062 outputs are used by the D075 system to forecast budget requirements (31).

C. Application Technique--The D062 and D075 systems are run on the ALCs' IBM 7080 computer system. The D062 system inputs and outputs are accessible at HQ. AFLC through CREATE (31). However, the D075 system is unique to the ALCs (31).

D. Decomposition--The D062/D075 systems forecast cost and requirements at the engine part level.

Inputs

A. Data Identification--The D062 data flow is presented in Figure 13.

1. The D032/D034A systems record recurring demands as those requisitions received from Air Force contractors, Security Assistance Program (SAP), Grant Aid, and other military services. During each EOQ semi-monthly cycle, the EOQ master demand file is updated (46:5-1) along with the returns and asset data. Two years demand history is maintained within the D062 data base.

2. The D033, AFLC Retail Stock Control and Distribution/Control Materiel Locator System, also provides demand data to D062. The D033 records, via computer action, a demand transaction when materiel is requisitioned from depot supply, whether it be by the maintenance shops or a tenant organization (46:3-1). The D033 also inputs depot supply operating levels and assets, along with demand frequencies, to D062 (46:5-7).

3. The D040, War Readiness Materiel Requirements and Spares Support Lists, provides the D062 the war materiel requirements for prepositioning EOQ items (46:5-5).

4. The D143B system interfaces with D062 to provide interchangeable groups of EOQ items (46:1-4).

5. The J005B, Standard Price Review Subsystem, inputs the most current EOQ price.

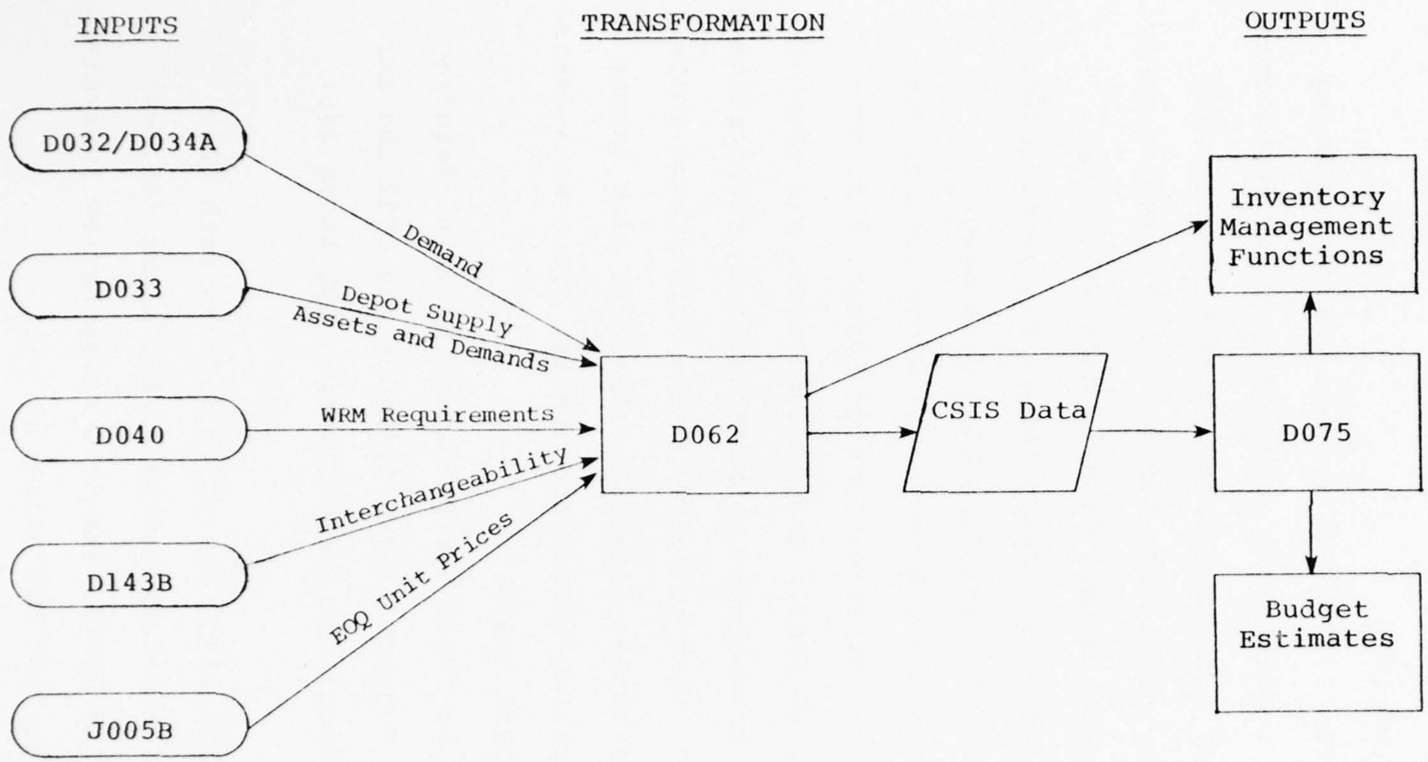

Figure 13

D062 Data Flow (46:4)

B. Source--Each input data base is automatically fed by computer tape into the D062 system under an iterative process of system application.

C. Characteristics of the Data--

1. The D033 system provides historical information on assets and demands.

2. The war materiel requirements are a programming estimate.

3. The interchangeability and substitutability between EOQ items is based on fact and historical information.

4. The unit prices for each EOQ item are the most current price.

D. Format--All the input data to the D062 is by computer tape from other systems.

Output

A. Format--A D062 output (D062.E1M0) provides EOQ quarterly requirements and unit EOQ cost as inputs to the D075 system for forecasting computations. There are many other outputs, but these are all associated with inventory management.

B. Time Frame--Because only two years of historical data is available, forecasted requirements are limited to two years.

C. Parameter Estimated--The D062 system interfaces with the D075 system to provide an output (D075.A5A0)

which forecasts EOQ costs by Federal Stock Classification, by TMS engine for the succeeding two years (31).

Summary of D062

The D062 system is used to project future requirements for base and depot EOQ items. The requirements computation is primarily accomplished by using a demand factor based on historical data. This historical data base is derived from item demands received through Air Force contractors, the Security Assistance Program, Grant Aid, other military services, depots, and defined WRM requirements. Costs are attached to these requirements by applying the most current item price. The cost forecasts are made for two years and used for budgetary purposes by IMs. A systems perspective of inputs and outputs of the D062 system is shown in Figure 13.

G072A, Depot Maintenance Production Cost System

Overview

The objective of the G072A system is to accumulate the cost of resources consumed in item repair within the ALC's Directorate of Maintenance and to provide a means of comparison with a "planned" or budgeted cost of operation (36:i). This system supports the cost accumulation objective by performing such functions as sales and work in progress reporting, as well as providing a multitude of monthly and other historical reports on operations (36:1-2).

Moreover, the system mechanically computes USPs for each TMS engine and each exchangeable NSN to recover depot operations cost for these commodities. The USPs also provide a standard to compare and evaluate actual operations. The goal of the maintenance industrial fund operation is to construct a USP so that revenues equal expenses.

The G072A derives the USP through an iterative process beginning with formulation of the Operating Cost Based Budget (OCBB). The G035A, Depot Maintenance Budget and Management Cost System, develops RCC expense rates from the OCBB data. The expense rates are transmitted to the G004C, Workload Programming, Planning, and Control Systems (35:9-1). The G004C then converts the RCC rates to workload pricing rates (hourly) for engines and exchangeable items. After review and approval by HQ. AFLC, these RCC pricing rates are used by the G072A system to produce USPs. This process is illustrated graphically in Figure 14.

As depicted in Figure 14, derivation of a USP is essentially a "grass roots" approach, requiring a voluminous amount of data. Since this data may not be available early in the deployment of new engines, the ALCs have done some USP estimation through analogy with existing engines (16). Unfortunately, this estimation technique does not provide good results for "new" technology engines (16). In these cases, the San Antonio ALC has found that 60 percent of the unit acquisition cost provides a good point estimate for

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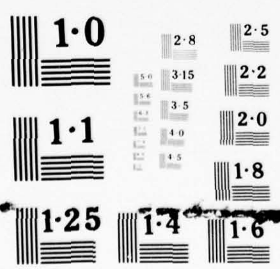

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

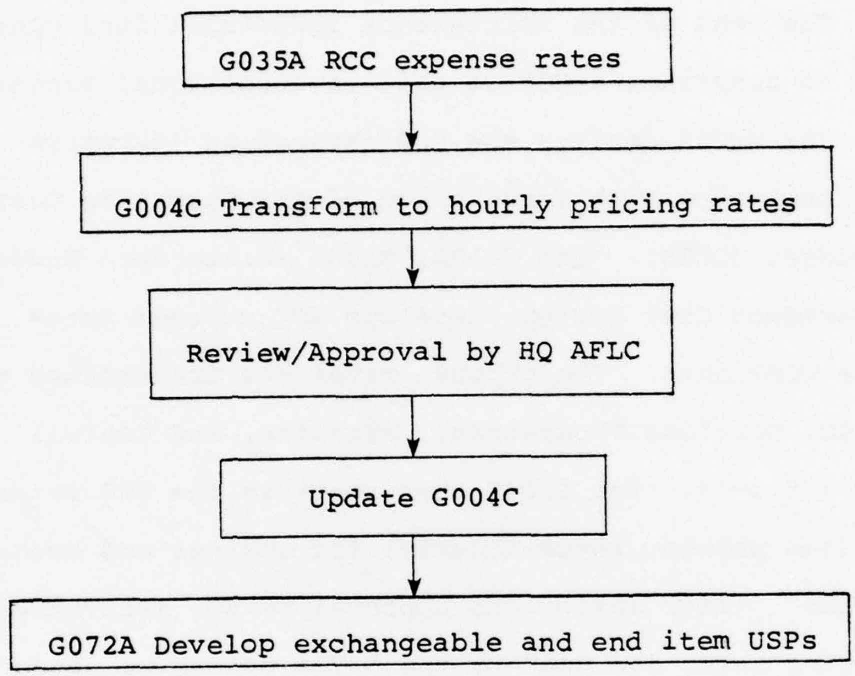

Figure 14

USP Formulation Process

depot overhaul cost (16). Another approach that is used for estimating depot costs for new engines, is to provide ALC engineers the design specifications, and, if possible, a prototype engine. The engineers provide estimates of the direct-labor hours within each RCC to overhaul that particular engine. These direct hours may then be costed using the current RCC revenue rates (16; 30), which are expressed as a rate per direct-labor hour. A summation of the RCC costs will provide a "per unit" cost of overhaul (16).

Exchangeables repair cost estimates have been derived using both of the techniques described above--analogy and the industrial engineering technique (30). Contractor estimates and data have also been used, but there are indications that their estimates for organic maintenance are too high (16).

Regardless of the technique used to estimate the initial cost of depot repair, the G072A, Depot Maintenance Production Cost System, will forecast "steady state" costs in the form of a USP.

General Model/Technique Characteristics

A. Type--The G072A aggregates projected cost from a low level of breakdown (RCC) to compute depot costs. As such, it uses an accounting methodology.

B. Use--The USP for each TMS engine is constructed by the G072A to offset expenses incurred by the Directorate of Maintenance, who functions as the seller. MMPP, the customer, forecasts budget figures by matching USPs to the computed requirements for engine overhauls and exchangeable repairs (30). The RCC rates, which drive the USP, also are used as work standards in depot maintenance management (36:1-2).

C. Application Technique--The CREATE computer system provides the USP. Matching requirements with the USP is done manually (some mechanized assistance) within MMPP and MMPD at the ALCs.

D. Decomposition--All operating costs are forecasted initially at the RCC or work center level without regard to a particular TMS engine or NSN exchangeable. Direct Product Standard Hour (DPSH) rates are then developed by the G004C system using this forecasted cost (35:6-1). The G072A uses these rates to accumulate cost from each RCC which results in a "price" for depot overhaul of each TMS engine and a "price" for each National Stock Number exchangeable (35:6-3). Even though the estimate itself--the USP--is a total engine or exchangeable figure, it is important to note that costs for depot maintenance may be tracked to the work center level.

Inputs

A. Data Identification--Cost fields are generated by the RCC Standard Cost Rates and Variance Factors, a tape subsystem of the G072A (23). These cost factors are matched against end item standards which are furnished by the G004L system. These standards are reflected as the number of direct product hours required for end item repair in each RCC (23).

B. Source--The G072A system initially receives the RCC Standard Cost Rates and Variance Factors from a card deck input of the G004C system (23). However, through sort processes, these rates are retained on tape by the G072A system for 730 days (36:4-10). The end item standards are also maintained on tape within G072A and retained for 730 days (36:4-7). These standards are computed based on inputs from the E046B (labor) and G004A (materiel) systems (36:4-7). The G072A system is accessible through the AFLC CREATE computer (23).

C. Characteristics of Data--The cost data is a "judgment" based on workload planning within an RCC and the experience of the individual(s) making the estimate (16). The number of DPSHs required for any TMS engine is determined by experience with periodic updating to keep the figures accurate (30).

D. Format--The data is provided to the G072A system by tape or card input.

Output

A. Format--The output generated is the End Item Product Cost Report (G072ACPAC) (36:4-13). This report is a computer printout which depicts each RCC's cost per DPSH for direct and indirect labor or material; overhead, variable and fixed; and general and administrative expenses. TMS engine DPSH requirements are also reflected for each RCC. The cost factors times the engine DPSH requirements provide the cost of engine repair in that RCC. A summary of the individual RCC's cost is accomplished then presented as the USP (23). The same presentation is made for exchangeables by NSN (23). The G072 also inputs exchangeable unit repair costs to the G019 system which subsequently is used in D041 calculations.

B. Time Frame--USPs are developed for each TMS engine for the current year and the budget year. Since the DMS,AFIF sales prices are subject to the DOD Rate Stabilization Program, the USPs are frozen unless there are indications of significant gains or losses (35:6-1). Consequently, detailed planning leads to a one-year forecast of a USPs that should provide a close approximation to actual cost (16; 62).

C. Parameter Estimated--The G072A System provides an estimate of depot overhaul costs for each TMS engine and repair costs for exchangeables by NSN. This estimate takes the form of a unit sales price.

Summary of G072A

The G072A system computes a Unit Sales Price (USP) for each TMS engine overhaul and exchangeable item. The projected depot work center, or RCC, expenses are forecasted by management for the budget year. These expenses are converted to a rate per Direct Product Standard Hour (DPSH) for each work center. The exchangeable and engine overhaul USPs are developed by multiplying the RCC DPSH rate times the number of DPSHs required for that item or engine in each work center; then accumulating all work center totals. A system perspective is shown in Figure 14.

Cost and Performance Ranking Model (COSPERANK)

Overview

The Cost and Performance Ranking Model was developed by Margaret Robinson, Operations Research Analyst, Engineering Services Division, Material Analysis Branch, Maintenance Data Section, Oklahoma ALC. This model is currently being reviewed for approval by HQ. AFLC. It is part of a larger program called Automated Cost and Performance Analysis (auto CPA). Auto CPA identifies substandard performance in five areas: (1) low reliability or high maintainability requirements; (2) the impact of changes to inspection requirements; (3) the distribution of maintenance actions across the inventory; (4) the verification of modification effectiveness; and (5) the causes of high rates for

unscheduled maintenance (29). Of most importance to this research is the COSPERANK portion of the program which calculates total annual support cost of a D041 recoverable item and predicts that item's future cost based on past performance and projected programs (29). A systems perspective can be gained by reference to Figure 15.

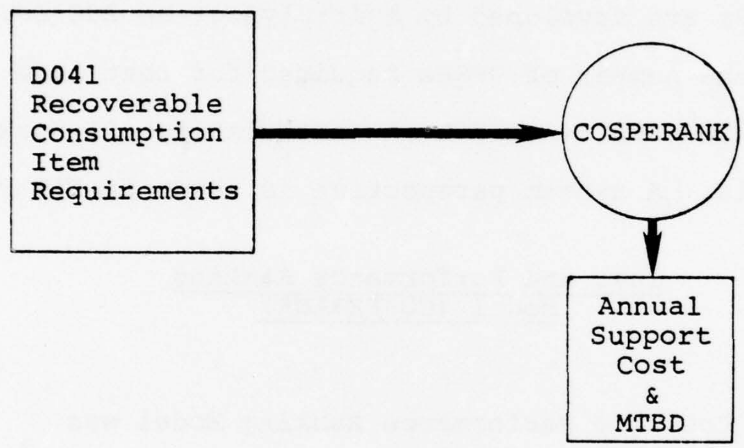

Figure 15

COSPERANK Model Source (29)

General Model/Technique Characteristics

A. Type--This is an accounting model which uses historical data and demand rates to project future demands and their associated costs.

B. Use--By calculating item annual support costs and Mean Time Between Demand (29), its ranking of a D041

item is valuable to the IROS (Increased Reliability of Operational Systems) programs, equipment specialists, engineers, and maintenance data personnel (29). This ranking by cost, with consideration of projected MTBD trends, allows for ready identification of those recoverable items which are cost drivers, or soon will be. With this knowledge, management attention can be focused on reduction of the costs of these O&S cost drivers through improving design or management control (29).

C. Application Technique--This model requires Fortran language and is run on the AFLC CREATE computer.

D. Decomposition--Estimates of annual support cost are provided down to the assembly level for D041 recoverable consumption items (29).

Inputs

A. Data Identification--The data used by this system can be obtained from the D041 system. It consists of NRTS percentages, average unit repair cost, condemnations, and demand rates (29).

B. Source--Data can be accessed from the D041 Recoverable Consumption Item Requirements Computation (29) computer system at Oklahoma City ALC.

C. Characteristics--The inputs are D041 estimates of future rates calculated from a 24-month moving average of data (29). Repair costs and unit prices are exceptions.

Repair cost is an estimate provided by HQ. AFLC/MAJ and unit price is based on the latest available information.

D. Format--The transformation to obtain annual cost output is accomplished by using the following equations:

Depot Support Cost =

(Total NRTS - Total SB & CR Condemnations) X (Average Repair Cost + Total SB & CR Condemnations X Unit Price)

Estimated Base Support Cost =

$$\text{Depot Support Cost} \times \left(\frac{100\%}{\text{NRTS}\ \% + .4\ (100\% - \text{NRTS}\%)} - 1 \right) +$$

Base Condemnations X Unit Price

These estimates are combined to give a total annual support cost for the item. MTBD is transformed to obtain an average MTBD for the past eight quarters and for the last two quarters. This data is then used to calculate a percentage of change in MTBD, then a least squares method calculates a trend line for MTBD (29).

Output

A. Format--The output is in the form of a computer printout.

B. Time Frame--The projections can be made for 25 quarters using the D041 system (29).

C. Parameter Estimated--The parameters estimated are total annual support cost and MTBD trends (29).

Summary of COSPERANK

This model provides the user with a ranking of D041 recoverable items based on annual support cost and Mean Time Between Demand (MTBD). This is accomplished by calculating annual support cost in terms of base maintenance, packaging and transportation cost, and depot overhaul cost, and then ranking them after considering MTBD. This item ranking provides an identification of cost drivers for exchangeables. The estimates are for twenty-five quarters, as in the D041.

SECTION C: THE MODELS/TECHNIQUES USED IN THE INDEPENDENT COST ANALYSIS PROGRAM

Logistics Support Cost Model (LSC)

Overview

The Independent Cost Analysis Division has redefined the basic LSC model so that only engine depot overhaul and base spares costs are forecasted (4). The model is intended for application in: (1) providing a depot overhaul cost estimate to differentiate between proposed designs during source selection, (2) establishing a baseline for contractual commitments, when appropriate, and (3) discriminating among design alternatives during full scale development (39:1-1; 4). However, the only

ICA applications to date have been as an independent cost estimate to support contractor and program inputs to the DSARC III production decision (4).

The ICA consolidates the engine estimates with other systems of the aircraft to project depot overhaul costs for the complete weapon system. A system is identified in Military Specification MIL-M-38769A by the first two numbers of a Work Unit Code (WUC) (39:1-1). The propulsion system is unique according to this criteria. The LSC model assumes that the computation only includes ". . . those logistics support costs associated with the weapon system, subsystems, and First Line Unit (FLU)[4] indenture levels [39:5]." The ICA, however, has included depot maintenance of Shop Replaceable Units (SRUs)--exchangeables within this context--as an add-on to the LSC estimates (4). This process is described in the model characterization under "Parameter Estimated." The ICA uses the following equations derived from the basic LSC Model (39:3-1,3-4; 4):

---

[4]A FLU is the first level of assembly that is removed and replaced as a unit when maintaining a system (39:1-1). ICA personnel indicate that the term FLU is synonymous with line replaceable unit (LRU) (4; 62).

Equation 1: Cost of FLU Spares

$$\underbrace{m\sum_{i=1}^{N} (STK_i)(UC_i)}_{\text{(Term 1)}} + \underbrace{\sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DRCT)}{MTBF_i} (UC_i)}_{\text{(Term 2)}}$$

$$+ \underbrace{\sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)(COND_i)}{MTBF_i}}_{\text{(Term 3)}}$$

Equation 3: Off Equipment Maintenance

$$\left. m\sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTFB_i} \left\{ NRTS_i \, [(DMH_i)(DLR + DMR)] + [2(NRTS_i) + COND_i] \, [(PSC)(1-OS) + (PSO)(OS) + (PSO)(OS)] (1.35W_i) \right\} \right\} \text{Term 1}$$

$$\left. + \frac{(TFFH)(EPA)(1-ERTS)}{CMRI} (EOH)(EUC) \right\} \text{Term 2}$$

In Equation 1, the first two terms reflect the cost of filling the depot and base repair FLU pipelines during periods of peak program activity. Term 3 computes the cost to replace failed FLUs which will be condemned over the system's life (39:3-4).

Term 1 in Equation 3 forecasts the labor and material cost to perform FLU depot repair, including transportation cost. Term 2 is the expected cost for labor and

material used to depot overhaul a complete engine (39:3-4; 4; 62).

General Model/Technique Characteristics

A. Type--The basic LSC equations used by ICA are an accounting process. However, the computations for the SRU add-on are statistical.

B. Use--The model output provides an estimate of engine depot overhaul costs as well as an estimate of the cost for FLU spares for the depot and base pipelines. To date, the only use of the estimates has been to provide an input to the DSARC III production decision (4).

C. Application Technique--The AFLC Computational Resources for Engineering and Simulation, Training, and Education (CREATE) computer system is used. ICA has reprogrammed the basic Equation 3 shown in the LSC User's Handbook to provide only depot maintenance costs. These costs are computed by year, for any given mission scenario (4).

D. Decomposition--Equations 1 and 3 forecast by accumulating costs from the section level. The SRU add-ons provide cost accrual from the assembly level.

Inputs

A. Data Identification--Tables 4 and 5 provide an extract from the LSC User's Handbook which identifies each variable in Equations 1 and 3 (39:2-1 thru 2-8).

TABLE 4

LSC MODEL VARIABLE IDENTIFICATION--EQUATION 1
(39:2-1 thru 2-8)

Variable	Description
STKi	Represents the number of FLU spares required to fill the base pipeline including a safety stock.
UCI	Expected FLU unit cost at the time of initial provisioning.
PFFH	Expected fleet flying hours for one month during peak usage period.
QPAi	Quantity of like FLUs within the system.
UFI	Ratio of operating hours to flying hours for a FLU.
I-RIPi	Fraction of FLU failures which cannot be repaired on base with removal.
NRTSI	Fraction of removed FLUs expected to be returned to the depot for repair.
DRCT	Weighted average depot repair cycle time in months.
MTFBi	Mean time between failures in operating hours of the FLU in the operational environment.
TFFH	Expected total force flying hours over the program inventory usage period.
CONDi	Fraction of removed FLUs expected to result in condemnation at base level.

TABLE 5

LSC MODEL VARIABLE IDENTIFICATION--EQUATION 3
(39:2-1 thru 2-8)

Variable	Description
DMHi	Average hours to perform depot maintenance on a FLU.
DLR	Depot repair rate.
DMR	Depot consumable material consumption rate.
PSC	Average packing and shipping cost to CONUS locations.
1-OS	Fraction of total force not deployed to overseas locations.
PSO	Average packing and shipping cost to overseas locations.
OS	Fraction of total force deployed to overseas locations.
Wi	FLU unit weight in pounds.
EPA	Number of engines per aircraft.
I-ERTS	Fraction of removed whole engines which are not returned to service by base maintenance.
CMRI	Combined maintenance removal interval.
EOH	Average cost for each engine overhaul expressed as a fraction of engine unit cost.
EUC	Expected unit cost of a whole engine.

B. Source--The LSC User's Handbook indicates that most of the data inputs on maintainability, cost, and engine performance parameters are provided by the contractor (39:2-1 thru 2-8). Since the ICA is providing an "independent" estimate, they normally obtain data on failure rates, maintenance hours, percentage of NRTS items, and other inputs that drive cost from ALC engineers and technicians (4). The ALCs derive this data, when requested by ICA, from design specifications and protypes (4). The program and engine system biographical data, i.e., flying hours, number of engines per aircraft, deployment rates, etc., is obtained from the Air Force office managing the program. Cost inputs are provided by contractors, through the Air Force program office, and the ALCs (4).

C. Characteristics of the Data--Since this estimate is provided relatively early in the acquisition process (DSARC III), most of the maintenance and reliability data is a "best guess" by ALC personnel using whatever historical information that is available (4).

D. Format--After data validation, card decks are created from the information provided by the ALCs, contractors, and Air Force program office. These card decks provide model inputs.

Output

A. Format--The LSC Model was originally designed to print a point estimate of system cost. ICA personnel

have reprogrammed the output formats to provide more management visibility in interpreting results (61). The output format under the ICA system will provide a breakout of FLU spares by depot and base pipelines, as well as a description of FLU off equipment maintenance (depot and/or base). The FLU off equipment transportation costs may also be displayed by overseas or CONUS deployment configuration (61).

B. Time Frame--ICA has developed their computer program to provide a "yearly" cost estimate so that any number of years may be projected (4). Most of the estimates they have done were for life cycle costing purposes--5, 10, or 15 years (4).

C. Parameter Estimated--The LSC Model provides an estimate of depot overhaul costs to the FLU indenture level for jet engines. After the LSC output is obtained, the ICA adds the cost of repair for SRUs by applying a percentage factor.

The SRU factor is mechanically developed using failure data from the D041 system to establish a cost relationship between SRUs and FLUs (4). This relationship is expressed as a percent of cost. For example, if it is determined that there is a correlation between the failure of a particular FLU and SRU, a "percentage of failure" factor is derived. This percentage is manually adjusted based on the comparative costs of the FLU and SRU to

reflect SRU failure as a percentage of the cost of the FLU failure (4).

Summary of LSC Model

The LSC Model is used by the AFLC Independent Cost Analysis Division to estimate the cost of engine depot overhauls. The model uses essentially an accounting process to forecast cost, with the inputs normally derived by ALC engineers from design specifications or prototypes. The estimates are used to provide an independent cost assessment for DSARC III decisions.

Cost Estimating Relationships (CER)

Overview

ICA has developed and published (AFLCP 173-4) Cost Estimating Relationships (CERs) that may be used to predict the overhaul and accessories repair costs for a turbine engine. Three CER equations were developed, one to estimate depot overhaul costs for turbo-jet engines without afterburner, and two equations which provide estimates of depot overhaul costs for turbo-fan engines. The turbo-fan engines were stratified into two groups by thrust rating to achieve better results (4). Because of poor statistical parameters obtained in CER development, the ICA recommended using a mean overhaul value for turbo-jet engines with afterburner (38:12).

The CERs and factors were based on a study of twenty-three turbine engines which were divided into the following sample:

Turbo-jet engines with afterburner - 9 TMS engines

Turbo-jet engines without afterburner - 9 TMS engines

Turbo-fan engines without afterburner - 5 TMS engines

Unit engine overhaul costs were obtained from DMS,AFIF USPs for fiscal year 1969 through fiscal year 1972 and entered into a multiple linear regression as the dependent variable (38:12). Eight engine characteristics were used as the independent variables. These independent variables are depicted in Table 6. A moving average technique was used to derive a cost per flying hour (FH) for forecasting engine accessories repair (28:12). The published models/factors are shown in Tables 7, 8, and 9.

TABLE 6

INDEPENDENT VARIABLES FOR CER DEVELOPMENT
(38:12-4)

Engine Dry Weight
Normal Thrust
Specific Fuel Consumption (Normal thrust)
Thrust to Weight Ratio (Normal thrust)
Maximum Thrust
Specific Fuel Consumption (Maximum thrust)
Thrust to Weight Ratio (Maximum thrust)
Incremental Thrust (Normal to maximum)

TABLE 7

CER USED FOR TURBO-JET ENGINES WITHOUT AFTERBURNER
(38:12-4)

$C = 84,651 - 66,816\ SFC$

C = engine overhaul cost

SFC: engine specific fuel consumption
(Maximum thrust)
(Sample range: .775 to 1.140)

Statistical Measures:

Coefficient of Correlation: -.920
Level of Significance: 99.5%
Standard Error of the Estimate: 3608

TABLE 8

FACTORS USED FOR ENGINE ACCESSORIES AND TURBO-JET ENGINES WITH AFTERBURNERS
(38:12-4)

<u>Engine Accessories (Exchangeables) Repair</u>

Turbo-jet engine with afterburner:	\$ 8.48 per FH
Turbo-jet engine without afterburner:	\$ 9.10 per FH
Turbo-fan engine without afterburner:	\$12.14 per FH

<u>Turbo-jet Engine with Afterburner</u>

Mean Overhaul Cost: \$29,154

TABLE 9

CER USED FOR TURBO-FAN ENGINES WITHOUT AFTERBURNER
(38:12-4)

EQUATION 1

$C = 22{,}006 + 1.392\ (NT)^3$

C: engine overhaul cost

NT: Normal thrust in thousands of pounds

(Sample range: 13.2 to 39.8)

Statistical measures:

Coefficient of Correlation: .99
Level of Significance: 99.9%
Standard Error of the Estimate: 919

EQUATION 2

(Used beyond the sample range of Equation 1)

$C = -23{,}784 + 3{,}319NT$

C: engine overhaul cost

NT: Normal thrust in thousands of pounds

Statistical measures:

Coefficient of Correlation: .99
Level of Significance: 99.5%
Standard Error of the Estimate: 5,147

General Model/Technique Characteristics

A. Type--Statistical.

B. Use--ICA uses the CERs to provide "order of magnitude" estimates when data is not available to use the LSC model. They are also used to check the estimates provided by contractors or when ICA uses some other method (4).

C. Application Technique--Manual computations are made using the published equations.

D. Decomposition--Total engine estimates for depot overhaul are provided by the CERs. The engine accessories repair factors provide an estimate of aggregate costs at the assembly level.

Inputs

A. Data Identification--Tables 7, 8, and 9 provide an identification of the data variables necessary to compute the estimates.

B. Source--The physical or performance data is obtained from the AFAPL or contractors. Flying hour data is provided by the program office managing the engine (4).

C. Characteristics of the Data--The flying hour data is an estimate. Specific fuel consumption and normal thrust may be an estimate or historical data depending on the state of engine development (4).

D. Format--Flying hours, SFC, and NT are entered into the model as absolute numbers.

Output

A. Format--The models compute a point estimate of engine overhaul and accessories repair cost. The statistical measures are depicted in Tables 7, 8, and 9 for the CERs. The negative coefficient of correlation for the "turbo-jet engines without afterburner" CER indicates an inverse relationship between SFC and overhaul cost, i.e., the lower the SFC, the higher the overhaul cost. Since a lower SFC is normally associated with larger, more complex engines (higher overhaul costs), this inverse relationship is appropriate (38:14). The statistical measures associated with the two CERs for turbo-fan engines imply a high level of confidence. However, it should be noted that the sample used to develop the equations is small (5 data points). This limited sample size may increase the risk of inaccurate cost estimates when using these CERs (38:14).

B. Time Frame--The CERs provide an overhaul cost for a particular engine expressed as a USP. The formula below is used to calculate the engine overhaul cost per aircraft per year:

$$\text{Engine Overhaul Cost Per Year} = \frac{(U)(\#E)(C)}{R}$$

U: Programmed Utilization Rate
#E: Number of Engines per aircraft
C: Engine Overhaul Cost (USP)
R: Engine Overhaul Removal Interval

The Programmed Utilization Rate and Engine Overhaul Removal Interval are provided as estimates from the responsible engine program office (4). Engine accessories repair cost is computed and added to the Engine Overhaul Cost Per Year to provide a total yearly cost for engine repair (38:15). This yearly figure may be multiplied by any number of years to forecast life cycle cost.

C. Parameter Estimated--Engine overhaul cost, engine accessories repair cost, and total engine repair costs are provided by these CERs and factors.

Summary of CERs

Cost Estimating Relationships (CERs) were developed by ICA to provide a cross-check to the LSC model results and an order of magnitude estimate when sufficient data is not available to use the LSC model. Various performance parameters, i.e., thrust to weight, specific fuel consumption, etc. are used to project overhaul costs. There has been some indication that these parameters do not provide an accurate cost estimate; consequently, there is a model being developed which uses engine physical characteristics, such as number of fan blades and material composition, as the independent variables.

SECTION D: SUMMARY

This chapter presented a characterization of the models identified during this research. Section B discussed

the models/techniques used by the ALCs for requirements and inventory forecasting. Costs are attached to these requirements for budgetary purposes. The COSPERANK model, presented in Section B, is an exception. It was included because of its potential in identifying cost drivers in the exchangeable area. Section C presented the models used by the Independent Cost Analysis Division at Headquarters, AFLC. These models are used in the acquisition decision process to estimate depot overhaul cost for jet engines. The chapter was constructed so that an individual model may be extracted for evaluation.

CHAPTER VI

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Chapter Overview

In Chapter I, the researchers stated their first objective was to "identify cost models and techniques used by the Air Force Logistics Command (AFLC) to estimate jet engine operation and support cost." This objective was satisfied by using the systematic research methodology of Chapter III, which led to an identification of the models/techniques characterized in Chapter V and shown at the top of Figure 16. The characterization format used in Chapter V is outlined in Figure 8, while a description of each characteristic is shown in Figure 4. These characteristics were specially selected to ensure that models subsequently presented would satisfy the second research objective. This objective was to exhibit the models/techniques in such a manner that AFAPL personnel could determine which models, if any, could be used in the design phase.

In accomplishing the two research objectives, certain facts concerning the models became evident. These facts are the basis for the primary findings in this chapter. These findings should provide the framework for the AFAPL to choose which models fit their needs. The facts also

allowed the researchers to make conclusions concerning the models/techniques used by AFLC for estimating jet engine O&S cost.

With this overview, the following outline will guide the reader through this chapter. Section A contains primary findings which were derived from the model characterization in Chapter V. Section B highlights the corollary findings, Section C presents the research conclusions, and Section D concludes with recommendations for further research.

To aid the reader in conceptualizing and interpreting the primary findings, two figures are incorporated in Section A. Figure 16 is a summarization of the model characterization. Figure 17 then displays a systems perspective of the uses and interrelationships of the models.

SECTION A: PRIMARY FINDINGS

Overview

The following format will be used in this section for the primary findings of this research effort: first, a major topic heading, such as General Model Characteristics, will be briefly discussed; second, primary findings will be given as they apply to the characteristics within that major area; finally, a brief summary of the research findings is provided.

	Model/Technique							
	D024	Engine Repair	D041	D062	G072A	COS-PERANK	LSC	CER
I General Model Characteristics								
A. TYPE								
1. Statistical								X
2. Accounting	X	X	X	X	X	X	X	
B. USE								
1. LCC							X	X
2. Budget	X	X	X	X	X			
3. Other						X		
C. APPLICATION TECHNIQUE								
1. Manual		X						X
2. Computer	X		X	X	X	X	X	
D. DECOMPOSITION								
1. Engine	X	X			X		X	X
2. Section	X	X			X			
3. Assembly			X		X	X	X	X
4. Part				X				
II Input								
A. DATA IDENTIFICATION (See Chapter V for specific information)								
B. SOURCE								
1. Computer Data Bank	X	X	X	X	X	X		
2. Required forms or documents		X						
3. Manual inputs			X				X	X
C. CHARACTERISTICS OF DATA								
1. Judgement	X		X		X			
2. Estimate	X		X	X	X	X		X
3. Historical	X	X	X	X	X	X	X	X
D. FORMAT								
1. Not Transformed	X	X	X	X	X			X
2. Transformed						X	X	
III Output								
A. FORMAT								
1. Computer	X		X	X	X	X	X	
2. Form		X						
3. Point estimate								X
B. TIME FRAME (in quarters)	24	20	25	8	4	25	∞	∞
C. PARAMETER ESTIMATED								
1. Cost				X	X	X	X	X
2. Quantity requirements		X	X	X				
3. Other	ARI							

Figure 16

Characterization Summary

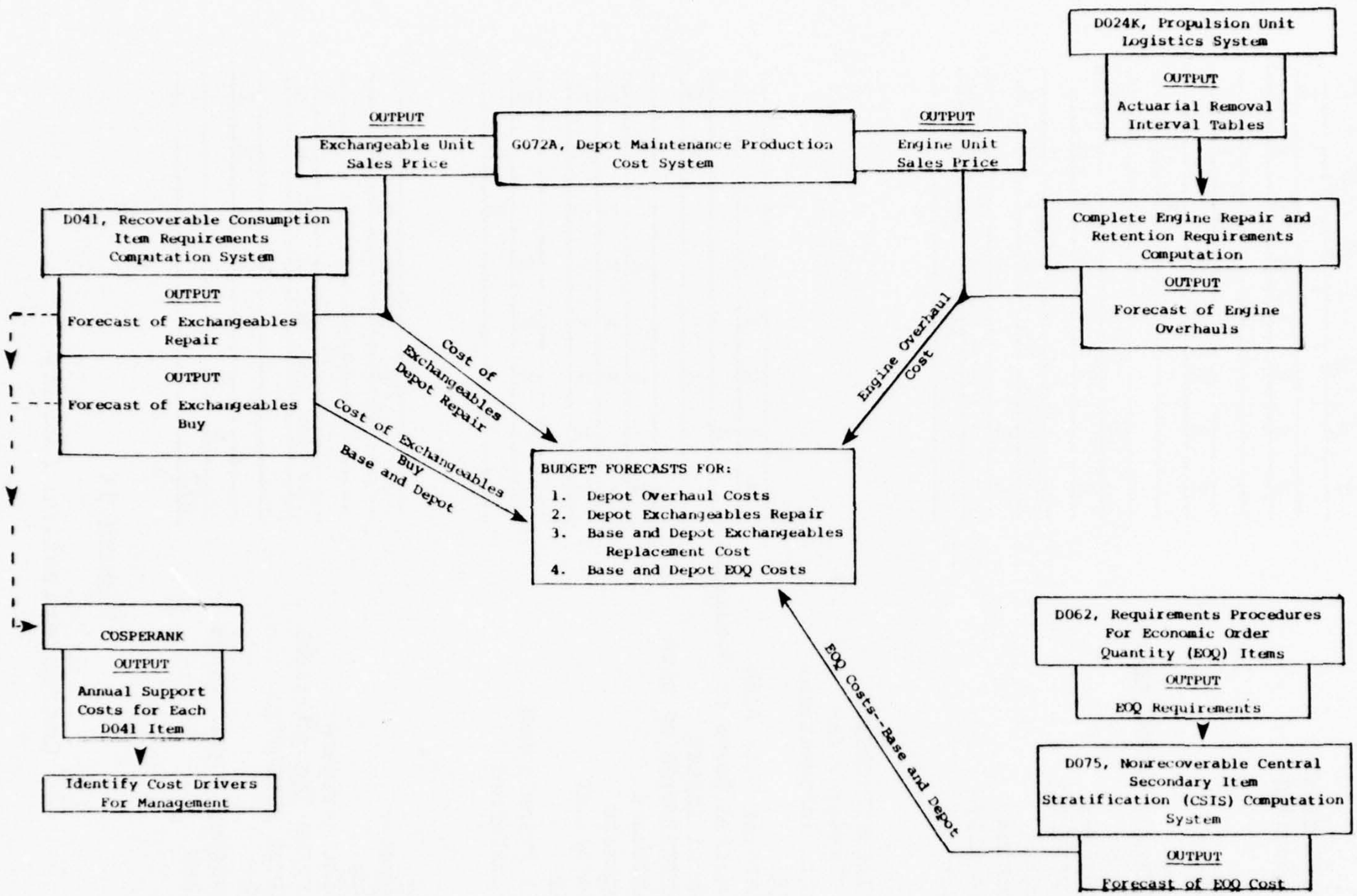

Figure 17

The AFLC Requirements/Cost Estimating Systems

General Model Characteristics

Introduction

The General Model Characteristics were defined to provide a conceptual understanding of each model/technique. They gave the type of model, what it is used for, how it is manipulated, and the engine level at which estimates are computed. The primary findings are a result of the similarities and differences among the models discussed in Chapter V. Figure 16 vividly portrays these similarities and differences.

Model/Technique Types

All of the models presented, except the CERs, use an accounting methodology to forecast cost or requirements. Consequently, detailed historical data is required to use these models. The CERs require only design or performance variables as inputs, so historical data is not required for CER applications. The accounting methodology is appropriate for most of AFLC's cost and requirements estimating because AFLC is normally forecasting for operational systems where historical maintenance, reliability, and cost data is available. When new systems are introduced, AFLC engine management uses "analogy with existing engines" or "expert judgment" to provide the inputs to the accounting models.

First Primary Finding

The D024, Propulsion Unit Logistics System; the Complete Engine Repair and Retention Requirements Computation; The D041, Recoverable Consumption Item Requirements Computation System; the D062, Requirement Procedures for Economic Order Quantity (EOQ) Items; the G072A, Depot Maintenance Production Cost System; the Cost and Performance Ranking model (COSPERANK); and the Logistic Support Cost (LSC) model, all use an accounting methodology to forecast cost and/or requirements. Some of the models use statistical "techniques" to derive factors, but they are not statistical models as defined in Chapter II. The only statistical models that were found within AFLC are the CERs used by the Independent Cost Analysis Division.

Model/Technique Uses

The D024, Complete Engine Repair and Retention Requirements Computation, D041, D062, G072A, and COSPERANK are used by the ALCs for annual support cost identification, workload planning, and budgetary management of operational systems. The LSC model and CERs are used by the Independent Cost Analysis Division at HQ. AFLC to provide LCC estimates for the DSARC III production decision.

Second Primary Finding

The only models used by AFLC for LCC estimates are the Logistics Support Cost model and CERs developed by the Independent Cost Analysis Division, HQ. AFLC.

Model/Technique Application Method

The only models/techniques that are not computer programmed are the Complete Engine Repair and Retention Requirements Computation and the CERs. All of the other models use the ALC's IBM 7080 computer for computations. The data and calculations are accessible through the HQ. AFLC CREATE system with the exception of the D075, Non-recoverable Central Secondary Item Stratification (CSIS) Computation System, which is unique to the ALCs.

Third Primary Finding

All of the AFLC requirement and cost forecasting models/techniques are accessible to a potential user through either obtaining proper read permission from the HQ. AFLC or the ALC office responsible for the computer models/ techniques, or coordination with the responsible office for models/techniques that are manually calculated.

Model/Technique Decomposition

The models/techniques presented provide a cost or requirements estimate across a spectrum of "engine" to "part" indenture levels. The D024 and the Complete Engine

Repair and Retention Requirements Computation forecast engine overhaul and removal intervals at the engine level or the section level, if the engine modular concept is applicable. The D041 system, COSPERANK, and the LSC model all project requirements and/or cost to the assembly level, while the D062/D075 forecast requirements/costs to the part level. The G072A computes a repair cost in the form of a USP for the D024 and D041 requirements computations at the engine, section (modular engines), and assembly levels. The CERs project cost at the engine and assembly levels. The decomposition of the various models is presented in Figure 16.

Fourth Primary Finding

There are models/techniques used by AFLC that project depot repair, and base/depot material cost and/or requirements at every engine level defined, i.e., engine, section, assembly, and part.

Model/Technique Inputs

Introduction

The "input" characteristics were defined to provide the AFAPL a background in model/technique data requirements. This was done so that a determination could be made on whether the data necessary to use the various models/techniques is available in the design phase. This section is

an integrated analysis of the following characteristics: data identification, source, characteristics of the data, and format.

Integrated Analysis of Inputs

Essentially, the following five classes of information are provided as inputs to all the models/techniques characterized: program data, historical data, published information, planning estimates, and data maintenance.

In order to compute a forecast using the D024; the Complete Engine Repair and Retention Requirements Computation; the D041; the LSC model; the CERs; and the D062/75 systems; future program data, such as flying hours and WRM operational requirements, must be used as an input. This data is an estimate that can be obtained from several sources. The computer-applied models receive this information through an interface with the program data files of the K008 computer system. The manual computation models use program data obtained from published documents or systems program offices of the Air Force Systems Command (AFSC).

Historical data used in the models consists of information such as item failures, computed factors, on-hand inventories, labor and material costs, and engine biographical data. Each model, except the CERs, use selected historical data as inputs. For the computer models, inputs

are provided from computerized data collection systems which interface directly with the model/technique. Historical data inputs to the manual models are usually obtained by extracting the information needed from computer outputs of the data collection systems.

Published information includes such things as ARI tables, safety levels, and base stock levels. Most of this information was developed to specify management guidelines on the system's operation. Consequently, published information is provided as an estimate which is used by the model/ technique to define the environment under which costs or requirements are estimated. In most cases, the published data is manually input to the model by referencing the appropriate document. However, in some of the systems the data is placed on a computer file which is automatically input to the model during calculations.

Planning estimates are used to provide a scenario and constraints for model use. This data includes such things as the workload schedule for the ALCs, budget projections by the ALC work centers, material standards, labor efficiency factors or standards, and, in some cases, design or performance specifications. The LSC model and the CERs both require planning estimates. ICA obtains thest estimates from the ALCs and AFSC system program offices. The other models also require planning estimates which are provided through computer files.

Data maintenance actions involve the update of the input data by the IM/EM or ICA cost analyst. When the models/techniques support operational systems, the IM/EM manipulate the data bases to reflect current or future conditions that will impact cost and/or requirements forecasting. ICA cost analysts also apply data maintenance, such as the use of escalation factors, to enhance the accuracy of the model/technique inputs.

Fifth Primary Finding

With the exception of the ICA CERs, all of the models/techniques identified in this research require detailed historical and estimated data.

Model/Technique Output

Introduction

Three output characteristics--format, time frame, and parameter estimated--were presented for each model/technique characterized. The analysis that follows integrates the output characteristics and the interrelationships of the models/techniques identified during this research effort to present a systems view of the AFLC cost estimating process. From this perspective, a finding on model/technique output is reported.

Analysis of Model/Technique Output

A systems perspective of the AFLC cost and requirements estimating process for engine management is shown in

Figure 17. The outputs of these models/techniques are only meaningful when the interrelationships are understood. Note that requirements are generated by the D041, the D062, and the Complete Engine Repair and Retention Requirements Computation. Moreover, costs are attached to these requirements by the G072A, Depot Maintenance Production Cost System for engine overhauls and exchangeables, while the D075, CSIS Computation System attaches cost for EOQ items. The exchangeable "buy" computations are priced within the D041 model calculations. COSPERANK stands alone as a model which identifies exchangeable cost drivers for management purposes. The other models, when used within the systems framework presented in Figure 17, are used for budgetary purposes. Consequently, the estimates are made for the current and budget year. Whenever these costs are forecasted outside the budget year, they are not adjusted for inflation or increases in labor, material, or item costs, even though the requirements computation may reflect estimates for these future years. The models/techniques shown are used for computing requirements and/or cost for all engines.

The LSC model and the CERs used by ICA differ from the preceding models discussed because they are not used for budgetary purposes. They are used to provide an independent judgment of the costs expected to be incurred

by AFLC during an engine's life. The outputs, therefore, are an estimate of the AFLC portion of LCC.

Sixth Primary Finding

The individual AFLC model or technique that is used to project requirements or cost is only meaningful when considered as part of the entire AFLC estimating process.

Summary of Primary Findings

Six primary findings were gleaned from the characterization of the individual models in Chapter V. These findings are as follows:

1. With the exception of the Independent Cost Analysis Division's CERs, all models identified were of the accounting type.

2. Only two of the models, the LSC model and the CERs, are used for LCC estimates.

3. All computerized models/techniques are available for use by contacting the responsible agency to obtain computer access permission. For manual models/techniques, the required information must be obtained directly from the using agency.

4. All engine levels identified in Figure 5 are estimated by AFLC models/techniques. Figure 16 readily identifies the model and associated engine levels.

5. With the exception of the ICA CERs, all of the models/techniques require detailed historical and estimated data.

6. The AFLC models/techniques are only meaningful when considered as part of the entire AFLC estimating process.

SECTION B: COROLLARY FINDINGS

Overview

The models/techniques reported in this research were identified using the methodology presented in Chapter III. From the facts in the model characterization in Chapter V, primary findings have just been explained. The corollary findings are the result of detailed investigation, discussions with AFLC personnel, and the researchers' perceptions of events that occurred during this research effort. The researchers felt that the addition of corollary findings would provide some of the insights gained by this team while researching jet engine O&S cost.

First Corollary Finding

The outputs of the requirements determination systems, such as D041 and D062, are based on historical data. This data is collected for the specific purpose of permitting estimation of future item demands. According to the model/technique users, once the engine has reached

a steady state condition and historical data is available, resultant estimates have proven reliable for demand forecasting. But, prior to the engine or part reaching a steady state of maturity, the forecasting of requirements is heavily reliant on accurate application of analogy with similar engines or parts. Judgmental inputs from engine management personnel also compensate for unforeseen differences between actual events and the analogous engine or part history.

The researchers feel that AFAPL design evaluations could benefit by using the present requirement models' historical demand rates to determine, through analogy, a part or section's impact on O&S cost. However, the strong assumption of such an analogy rests on the premise that the newly designed part will follow the "same" burn-in period and stabilize at the same steady state demand conditions. The validity of this assumption must be evaluated for each new part, section, or engine, if analogy is to be used.

Second Corollary Finding

During this research effort, discussions with AFLC requirements personnel revealed that a potential exists for developing a simulation model which could determine the impact of design changes on O&S cost. Design changes on parts or assemblies which drive base maintenance removal intervals, overhaul removal intervals, level of repair,

MOT, or consumable/exchangeable classifications, do affect O&S cost. Such a simulation model would require the integration of several of the models presented. Consequently, the model would require a great deal of design and testing to develop. One benefit of this simulation model would be its use of the same requirement systems that would ultimately manage the part, section or engine within AFLC. This would allow long term evaluation of the simulation model's accuracy.

Third Corollary Finding

Demand rates are not synonymous with failure rates. For example, during disassembly of an engine for overhaul, certain parts are destroyed or determined unsalvageable. A demand for these replacement parts is generated in both these instances, but the part has not actually failed. The researchers felt this distinction was important because the determination of O&S cost is frequently based on failure rates, e.g., the LSC model. Consequently, the utilization of failure rates during design in determining part requirements may not always be valid.

Fourth Corollary Finding

Within AFLC, reliance is often placed on the technical expertise of the ALCs' engineering staff to provide accurate estimates for the various "cost drivers," such as, labor hours for engine overhaul, and demand rates for

LRUs. This expertise is used by the Production Management Branch at the ALCs for estimating workload requirements and budgets for new engines. The AFLC Independent Cost Analysis Division also uses information from this staff for the LSC model inputs.

The researchers were not in a position to make qualitative judgments on the contribution of the engineering staff or validate the reliability of their estimates. However, the very real fact that they participate and observe the impact of redesign efforts through engineering change proposals identifies them as a potential source to assess the cost impact of part or assembly design changes.

Summary of Corollary Findings

The corollary findings offered the researchers a chance to help others gain an insight into the AFLC cost estimating system. The following is a brief summary of these corollary findings:

1. The D062 and D041 systems may provide the data base from which an analogy could be used to assess the cost of design alternatives.

2. The potential exists for simulation of the AFLC requirements determination systems. This simulation model could aid in design tradeoffs.

3. Demand rates, used by the AFLC requirements systems, are not synonymous with failure rates.

4. The ALCs' engineering staff could provide the AFAPL additional expertise on the O&S cost impact of design changes.

SECTION C: CONCLUSIONS

The conclusions in this section are the logical extensions of the primary findings of Section A. These conclusions are the culmination of the research and have meaning within the context of this effort. The models identified represent a sample and are not intended to represent a census of all the models/techniques used by AFLC. However, discussions with engine management personnel confirm the models presented herein identify the major determiners of O&S cost. With this in mind, the researchers present the following conclusions.

1. With the exception of the LSC model and ICA CERs, AFLC does not have models defined that specifically estimate LCC.

2. The models used for requirements determinations and short range budget predictions are accurate and well adapted for their intended use. But, as indicated above, they cannot be used to estimate the AFLC portion of O&S cost in their present form. However, the researchers have concluded that these models/techniques could be modified to provide estimates for life cycle costing purposes.

3. Two engines were selected for tracking the cost estimating process at the ALCs to determine if there was any difference in the models/techniques used for modular engines. From this investigation, the researchers concluded that the models/techniques identified within AFLC are used to estimate costs and/or requirements for any engine, including engines with modular design.

SECTION D: RECOMMENDATIONS FOR FURTHER RESEARCH

One of the frustrations of any research effort is that avenues continually present themselves for expansion of the research effort, but the very real constraints of time and resources preclude the pursuit of these potentially fruitful endeavors. Below is a list of recommended research topics which could further current knowledge in the area of O&S cost estimation, and/or support the objectives of reducing life cycle cost.

1. The researchers concluded that the requirements and cost computation models may be useful, after some modification, for estimating O&S cost. To implement this conclusion, a research effort should be undertaken to identify the data available during the design phase; compare this data against model requirements; attempt to revise the model to accommodate shortcomings; then forecast that portion of O&S cost provided by the model. The engine used should be one which has reached operational maturity so

that estimated O&S cost could be compared with actual cost to validate or invalidate the model for use during the design phase. The D041 system is recommended because of the large dollar value of the components it tracks. Also, the exchangeable repair costs are, for the most part, centralized at the ALC making data collection an accomplishable task.

2. Another fruitful area for further research could be a validation of the COSPERANK model. If COSPERANK is validated, it could be used to predict cost drivers for D041 jet engine recoverable items by master stock number. The AFAPL could then concentrate on design changes to these "cost drivers" to reduce engine LCC.

3. Managers in the D062 and D041 systems indicated that the moving average technique provides accurate forecasts for most inventory items, but not all. For some items, the forecasts are sufficiently inaccurate to warrant continual manual adjustments to the requirements output. The application of other statistical techniques, such as exponential smoothing and time series analysis, may be more appropriate than the moving average used now.

APPENDICES

APPENDIX A

O&S COST ELEMENT DEFINITIONS FROM THE DOD OPERATING SUPPORT COST DEVELOPMENT GUIDE FOR AIRCRAFT SYSTEMS (57)

Squadron Operations

Combat Command Staff Manpower. The cost of paying the personnel required for flying supervision. These personnel perform such jobs as command, operations control, planning and scheduling, flying safety, quality control on aircrew training and flying proficiency and include the combat commander, his staff and the squadron commanders and their respective staff.

Aircrew Manpower. The cost of paying the full complement of crews required to man unit aircraft. This includes all of the crews necessary for the efficient operation of the unit in meeting combat readiness requirements; training requirements; and administrative requirements such as leave, sickness, TDY, etc.

Base Aircraft Maintenance Manpower. The cost of paying the personnel needed to meet base level maintenance requirements of the operational squadron. This includes manpower needed to meet the direct maintenance demands of the assigned aircraft and ground equipment, to provide for maintenance supervision and to cover administrative requirements such as leave, sickness, TDY, etc.

Base Munitions Maintenance Manpower. The cost of paying personnel needed for: loading, unloading, arming and dearming of squadron munitions; inspection, testing and maintenance of all aircraft weapons release systems; maintenance, ammunition loading, activation and deactivation of aircraft gun systems; and maintenance and handling of the munitions stockpile authorized by WRM plan.

Aircraft Security Manpower. The cost of paying personnel needed for aircraft equipment security: For example, entry control, close and distant boundary support, and security alert teams.

Aviation POL. The cost of buying Petroleum, Oil and Lubricants (including fuel additives) used by the Squadron aircraft.

Base Aircraft Maintenance Materiel. The cost of purchasing materiel from the General and System Support Division of the Stock Fund. This includes all non-reparable expense type items including aircraft, electronic and communication repair parts, and base operating consumables used in the organizational, periodic, or field maintenance activities at base level.

Miscellaneous Personnel Support. The cost of supplies, services and equipment needed to support aircraft unit personnel. This includes administrative supply items, expendable equipment and office machines, custodial services and other personnel-oriented support items (desks, chairs, etc.).

Base Operating Support

Base Services Manpower. The cost of paying those base personnel necessary to directly support aircraft unit personnel. Base functions which directly support squadron personnel include activities such as food service, supply, motor pool and payroll operations. The sum of these costs represent the pay of those base people who would leave the base if the operating requirement were to move elsewhere.

Miscellaneous Personnel Support. The cost of supplies and equipment needed to support base personnel who directly support aircraft unit personnel. This includes administrative supply items, expendable equipment and office machines, custodial services and other personnel-oriented support items (desks, chairs, etc.).

Logistics Support

Depot Maintenance Manpower and Materiel. The cost of materiel and the pay of people required to perform major overhaul of aircraft including complete rebuilding and manufacture of parts. This maintenance involves greater technical capability and more extensive facilities than are available at base level.

Supply Depot Manpower and Materiel. The cost of materiel and salaries of depot and base personnel needed to perform the distribution of aircraft supplies and parts to and from supply depots to points of use or repair.

Second Destination Transportation. The cost of shipping supplies and materiel needed to support aircraft unit equipment and personnel. These costs include shipment of spare and repair parts to and from the repair depots.

Personnel Support

<u>Recruit/Technical Training Manpower</u>. The cost of paying personnel in training who will replace unit personnel.

<u>Undergraduate Pilot/Navigator Training</u>. The cost of paying personnel in training who will replace unit aircrews and the cost of their instruction including the pay of instructor personnel.

<u>Medical Manpower</u>. The cost of paying medical personnel needed to provide medical support to: aircraft unit personnel; base personnel who provide direct support to the aircraft unit; and training pipeline personnel.

<u>Medical Materiel</u>. The cost of materiel required to support aircraft unit personnel; base personnel who provide direct support to the aircraft units, and training pipeline personnel.

<u>Permanent Change of Station (PCS)</u>. The costs incident to the PCS of: aircraft unit military personnel either individually or as organized units; base personnel who provide direct support to the aircraft unit; and training pipeline personnel.

<u>Miscellaneous Personnel Support</u>. The cost of expendable supplies and equipment needed by instructor, trainee and medical personnel who support aircraft unit personnel.

Recurring Investment

<u>Replenishment Spares</u>. The cost of procuring aircraft assemblies, spares and repair parts which are normally repaired and returned to stock. In addition, it includes procurement of stock levels that are not provided by initial spares procurement. These are centrally managed investment type items. War Readiness Materiel is excluded.

<u>Recurring (Class IV) Modifications</u>. The cost of modifying aircraft, ground equipment, and training equipment that are in the operating inventory to make them safe for continued operation, to enable them to perform mission essential tasks (not new capability), and to improve reliability or reduce maintenance cost. Includes spares.

<u>Common Aircraft Ground Equipment</u>. The cost of procuring common ground servicing equipment, maintenance

and repair shop equipment, instruments and laboratory test equipment, and other miscellaneous items including spares for this equipment. Covers such items as ground generators, jet engine test stands, test sets for radios, radars and fire control systems, hand tools, compressors, gages and other minor items. These equipment demands are generated by a need to: (1) replace peculiar support equipment bought using aircraft procurement funds; (2) obtain common, off-the-shelf ground equipment that are needed to support aircraft operations as production aircraft arrive in the operating inventory; and (3) replenish common ground equipment that is no longer reparable.

Training Munitions. The cost of munitions expended by the Unit for the purpose of keeping aircrews proficient in weapons delivery techniques.

Training Missiles. The cost of missiles expended by the Unit for the purpose of keeping aircrews proficient in weapons delivery techniques.

APPENDIX B

PILOT STUDY RESULTS

A pilot study was conducted to determine, first, if O&S cost estimating was being performed within the Air Force Logistics Command; second, to determine where it was being performed; third, to determine the appropriateness of the population delimitation; and finally, to validate the data collection plan. Initial discussions with cost analysis, budget, and engine management personnel at AFLC (see Appendix E) revealed that cost estimating models/ techniques could be found at Oklahoma and San Antonio ALCs and at other major command headquarters. As a result, telephone discussions were conducted with cost analysts, budget analysts, and engine managers at selected major commands (Appendix D).

The results of this pilot study indicated that some training costs for jet engines are being estimated by ATC cost analysts. MAC's engine managers periodically estimate O&S cost for jet engines using various models/ techniques. Discussions with the Chief, Management Division at each of the ALCs mentioned above revealed that they are also involved in jet engine O&S cost estimation.

APPENDIX C

DISCUSSION OBJECTIVES GUIDE

I. <u>Cost Estimation Process</u>

A. Identify the unit's position in the organizational structure.

B. Determine the relationship of this unit to the budget, cost analysis, and engine management functions.

C. Determine any estimation responsibilities, formal or informal, for jet engines.

II. <u>Kinds of Models/Techniques</u>

A. Identify any models/techniques used to estimate engine cost or drivers of cost.

B. Identify the type of models or techniques used.

C. Determine the lowest level of engine breakdown used in the model/technique.

D. Identify the approximate number of manhours normally required to collect data and manipulate or interpret output.

III. Model/Technique Characteristics

A. Identify the types of data required.

B. Determine the source of input data.

C. Define the characteristics of the input data.

D. Identify the method of data transformation.

IV. Model/Technique Uses

A. Identify the parameters which are estimated by the model/technique.

B. Determine the time frame the model was created to estimate.

C. Define the output format.

D. Identify how the output has been used, i.e., to provide estimates for source selection, DSARC decisions, etc.

APPENDIX D

LIST OF INDIVIDUAL CONTACTS AT MAJOR COMMANDS

INDIVIDUALS CONTACTED DURING PILOT STUDY

Strategic Air Command (SAC)

Captain Tom Roberts
ACMC/271-4794
HQ. SAC/Cost Analyst

Captain James W. Brannock
LGMS/271/4958
HQ. SAC/Command Engine Manager

Air Traffic Command (ATC)

Mr. Mike Eaton
ACMW/487-4733
HQ. ATC/Cost Analyst

Mr. W. H. Richeson
ACB/487-5543
HQ. ATC/Deputy Budget Director

Mr. Paul A. Records
LGMAA/487-2593
HQ. ATC/Command Engine Manager

Air Defense Command (ADC)

Captain Don H. Owen
ACMAC/692-3216
HQ. ADC/Cost Analyst

Mr. Mike Bauman
LGMW/692-3673
HQ. ADC/Command Engine Manager

Military Airlift Command (MAC)

Captain Scott Koener
ACMC/658-4406
HQ. MAC/Cost Analyst

Captain Toni Ogletti
ACDO/638-2569
HQ. MAC/Budget Officer

Mr. Don Lukens
LGSWL/638-2020
HQ. MAC/Command Engine Manager

Tactical Air Command (TAC)

Captain Roger M. Whitney
ACMC/432-7001
HQ. TAC/Cost Analyst

Captain Dick Gannell
ACBOM/432-2881
HQ. TAC/Budget Analyst

Major James M. Shipman
LGMS/432-7571
HQ. TAC/Weapon System Support,
Engine Management Division Chief

APPENDIX E

LIST OF INDIVIDUAL CONTACTS AT HEADQUARTERS AFLC

HEADQUARTERS AFLC

*Mr. Robert P. Boulais, Cost Analyst
DCS Comptroller
Directorate of Management and Budget (ACRCC)
Estimation Responsibilities: Independent Cost Analysis

*Major Gary Brown, Chief, Financial Management Division
DCS Comptroller
Directorate of Management and Budget (ACR)
Estimation Responsibilities: Budget

*Mr. Thomas Harruff, Chief, Requirements, Procedures, and Analysis
DCS Logistics Operations
Propulsion Systems Directorate (LOPR)
Estimation Responsibilities: Engine Cost Drivers, e.g., Number of overhauls per year, mean time between failure, etc.

*Mr. Jim Kelly, Chief, Directorate of Industrial Fund Management
DCS Maintenance
Directorate of Industrial Fund Management (MAJ)
Estimation Responsibilities: Industrial Fund Charges

*Mr. Walter Melloncamp, Chief, Directorate of Materiel Requirements
DCS Logistics Operations
Directorate of Materiel Requirements (LORE)
Estimation Responsibilities: Budget Estimates for Engine Depot Support

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*Identified offices/individuals contacted during the pilot study.

APPENDIX F

LSC MODEL DATA ELEMENTS (39:2-1 thru 2-9)

Weapon System Variables

1. EBO - Standard established for expected backorders--the expected number of unfilled demands existing at the lowest echelon (bases) at any point in time.

2. IMC - Initial management cost to introduce a new line item of supply (assembly or piece part) into the Air Force inventory.

3. M - Number of intermediate repair locations (operating bases).

4. MRF - Average manhours per failure to complete off-equipment maintenance records.

5. MRO - Average manhours per failure to complete on-equipment maintenance records.

6. NSYS - Number of systems within the weapon system.

7. OS - Fraction of total force deployed to overseas locations.

8. OST - Weighted average Order and Shipping Time in months. The elapsed time between the initiation of a request for a serviceable item and its receipt by the requesting activity. CONUS locations are input as OSTCON. Overseas locations are input as OSTOS. OST = (OSTCON)(1-OS) + (OSTOS)(OS)

9. PFFH - Peak Force Flying Hours--expected fleet flying hours for one month during the peak usage period.

10. PIUP - Operational service life of the weapon system in years. (Program Inventory Usage Period)

11. PMB - Direct productive manhours per man per year at base level (includes "touch time," transportation time, and setup time).

12. PMD - Direct productive manhours per man per year at the depot (includes "touch time," transportation time, and setup time).

13. PSC - Average packing and shipping cost to CONUS locations.

14. PSO - Average packing and shipping cost to overseas locations.

15. RMC - Recurring management cost to maintain a line item of supply (assembly or piece part) in the wholesale inventory system.

16. SA - Annual base supply line item inventory management cost.

17. SR - Average manhours per failure to complete supply transaction records.

18. TD - Average cost per original page of technical documentation. The average acquisition cost of one page of the reproducible source document (does not include reproduction costs).

19. TFFH - Expected Total Force Flying Hours over the Program Inventory Usage Period.

20. TR - Average manhours per failure to complete transportation transaction forms.

21. TRB - Annual Turnover rate for base personnel.

22. TRD - Annual Turnover rate for depot personnel.

Propulsion System Peculiar Variables

1. ARBUT - Engine Automatic Resupply and Buildup Time in months.

2. BP - Base engine repair cycle time in months.

3. CMRI - Combined Maintenance Removal Interval. Average engine operating hours between removals of the whole engine.

4. CONF - Confidence factor reflecting the probability of satisfying a random demand for a whole engine from serviceable stock to replace a removed engine.

5. DP - Depot engine repair cycle time in months.

6. EOH - Average cost per overhaul of the complete engine at the depot expressed as a fraction of the engine unit cost (EUC) including labor and material consumption. Repair and stockage of engine components considered elsewhere as FLUs is not included.

7. ERTS - Return rate for engines. Fraction of removed whole engines which are returned to service by base maintenance. [The complement, (1-ERTS), is the fraction which must be sent to depot for repair/overhaul].

8. EPA - Number of engines per aircraft.

9. ERMH - Average manhours to remove and replace a whole engine including engine trim and runup time.

10. EUC - Expected Unit Cost of a whole engine.

11. FC - Fuel cost per unit.

12. FR - Fuel consumption rate of one engine in units per flying hour.

13. LS - Number of stockage locations for spare engines.

System Variables

1. BCA - Total cost of additional items of common base shop support equipment per base required for the system.

2. BAA - Available work time per man in the base shop in manhours per month.

3. BLR - Base labor rate.

4. BMR - Base consumable material consumption rate. Includes minor items of supply (nuts, washers, rags, cleaning fluid, etc.) which are consumed during repair of items.

5. BPA - Total cost of peculiar base shop support equipment per base required for the system which is not directly related to repair of specific FLUs or when the quantity required is independent of the anticipated workload (such as overhead cranes and shop fixtures).

6. BRCT - Average Base Repair Cycle Time in months. The elapsed time for a RTS item from removal of the failed item until it is returned to base serviceable stock (less time awaiting parts). For FLUs of the "black box" variety (e.g., avionics LRUs), the repair of which normally consists of removal and replacement of "plug-in" components (SRUs).

7. CS - Cost of software to utilize existing Automatic Test Equipment for the system.

8. DCA - Total cost of <u>additional</u> items of common depot support equipment required for the system.

9. DAA - Available work time per man at the depot in manhours per month.

10. DLR - Depot labor rate.

11. DMR - Same as BMR except refers to depot level maintenance.

12. DPA - Same as BPA except relates to depot support equipment.

13. DRCT - Weighted average Depot Repair Cycle Time in months. The elapsed time for a NRTS item from removal of the failed item until it is returned to depot serviceable stock. This includes the time required for base-to-depot transportation and handling and the shop flow time within the specialized repair activity required to

repair the item. Contractual repair, input as DRCTC. Organic repair input as DRCTO.

$$DRCT = (DRCTC)(1-OS) + (DRCTO)(OS)$$

14. FB - Total cost of new base facilities (including utilities) to be constructed for operation and maintenance of the system, in dollars per base.

15. FD - Total cost of new depot facilities (including utilities) to be constructed for maintenance of the system.

16. FLA - Total cost of peculiar flight-line support equipment and additional items of common flight-line support equipment per base required for the system.

17. H - Number of pages of depot level technical orders and special repair instructions required to maintain the system.

18. IH - Cost of interconnecting hardware to utilize existing Automatic Test Equipment for the system.

19. JJ - Number of pages of organizational and intermediate level technical orders required to maintain the system.

20. N - Number of different FLUs within the system.

21. SMH - Average manhours to perform a scheduled periodic or phased inspection on the system.

22. SMI - Flying hour interval between scheduled periodic or phased inspections on the system.

23. SYSNOUN - Name of the system--up to 60 alphanumeric characters.

24. TCB - Cost of peculiar training per man at base level including instruction and training materials.

25. TCD - Cost of peculiar training per man at the depot including instruction and training materials.

26. TE - Cost of peculiar training equipment required for the system.

27. XSYS - System identification. The assigned five-character alphanumeric Work Unit Code of the system.

First Line Unit (FLU) Variables

1. BCMH - Average manhours to perform a shop bench check, screening, and fault verification on a removed FLU prior to initiating repair action or condemning the item.

2. BMC - Average cost per failure for a FLU repaired at base level for stockage and repair of lower level assemblies expressed as a fraction of the FLU unit cost (UC). This is the implicit repair disposition cost for a FLU representing labor, material consumption, and stockage of lower indenture repairable components within the FLU (e.g., shop replaceable units or modules).

3. BMH - Average manhours to perform intermediate-level (base shop) maintenance on a removed FLU including fault isolation, repair, and verification.

4. COND - Fraction of removed FLUs expected to result in condemnation at base level.

5. DMC - Same as BMC except refers to depot repair actions.

6. DMH - Same as BMH except refers to depot-level maintenance.

7. FLUNOUN - Word description or name of the FLU--up to 60 alphanumeric characters.

8. IMH - Average manhours to perform corrective maintenance of the FLU in place or on line without removal including fault isolation, repair, and verification.

9. K. - Number of line items of peculiar shop support equipment used in repair of the FLU.

10. MTBF - Mean Time Between Failures in operating hours of the FLU in the operational environment.

11. NRTS - Fraction of removed FLUs expected to be returned to the depot for repair.

12. PA - Number of new "P" coded reparable assemblies within the FLU.

13. PAMH - Average manhours expended in place on the installed system for Preparation and Access for the FLU; for example, jacking, unbuttoning, removal of other units and hookup of support equipment.

14. PP - Number of new "P" coded consumable items within the FLU.

15. QPA - Quantity of like FLUs within the parent system. (Quantity per Application)

16. RIP - Fraction of FLU failures which can be repaired in place or on line without removal.

17. RMH - Average manhours to fault isolate, remove, and replace the FLU on the installed system and verify restoration of the system to operational status.

18. RTS - Fraction of removed FLUs expected to be repaired at base level.

19. SP - Number of standard (already stock-numbered) parts within the FLU which will be managed for the first time at bases where this system is deployed.

20. UC - Expected unit cost of the FLU at the time of initial provisioning.

21. UF - Ratio of operating hours to flying hours for the FLU.

22. W - FLU unit weight in pounds.

23. XFLU - FLU identification. The assigned five-character alphanumeric Work Unit Code of the FLU.

<u>Support Equipment Variables</u>

1. BUR - Combined utilization rate for all like items of support equipment--base level.

2. CAB - Cost per unit of peculiar support equipment for the base shop.

3. CAD - Same as CAB except refers to depot support equipment.

4. COB - Annual cost to operate and maintain a unit of support equipment at base level expressed as a fraction of the unit cost (CAB).

5. COD - Same as COB except refers to depot support equipment.

6. DOWN - Fraction of downtime for a unit of support equipment for maintenance and calibration requirements.

7. DUR - Same as BUR except refers to depot support equipment.

8. XSE - SE identification--up to 20 alphanumeric characters.

APPENDIX G

LSC MODEL EQUATIONS NOT CHARACTERIZED (57:3-3, 3-5 thru 3-13)

C_2 = On-Equipment Maintenance

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} [PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i)] \, (BLR)$$

$$+ \frac{TFFH}{SMI} (SMH)(BLR) \quad + \boxed{\frac{(TFFH)(EPA)}{CMRI} (ERMH)(BLR)}$$

The first term in C_2 is the labor manhour cost to perform on-equipment (flight line) maintenance on FLUs due to (unscheduled) failures over the life of the system. The element,

$$PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i)$$

is the weighted average on-equipment maintenance manhours per failure of the i^{th} FLU including Preparation and Access time and either in-place repair or removal and replacement as appropriate.

The second term is the labor manhour cost to perform scheduled maintenance on the complete system over the life cycle.

The third term is applicable only when dealing with a propulsion or powerplant system. It is the maintenance manhour cost to remove and replace whole engines on the aircraft.

C_4 = Inventory Management Cost

$$= [IMC + (PIUP)(RMC)] \sum_{i=1}^{N} (PA_i + PP_i + 1)$$

$$+ (M)(SA)(PIUP) \sum_{i=1}^{N} (PA_i + PP_i + SP_i + 1)$$

The first term in C_4 is the cost to enter new line items of supply into the government inventory and to manage them over the life of the system.

The second term is the life cycle base level supply management cost of these new items of supply as well as common, already stock-numbered items which will be carried for the first time in base supply where this system is deployed.

C_5 = Cost of Support Equipment

$$= \sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTBF_i}$$

$$\sum_{j=1}^{K} \left\{ \frac{(RTS_i)(BMH_i + BCMH_i)}{(BUR_j)(BAA)(1-DOWN_j)} [1 + (PIUP)(COB)_j)] \; CAB_j \right.$$

$$\left. + \frac{(NRTS_i)(DMH_i)}{(DUR_j)(DAA)(1-DOWN_j)} [\, 1 + (PIUP)(COD_j)] \; CAD_j \right\}$$

$$+ \; [1 + 0.1(PIUP)][DCA + DPA + M(BCA + BPA + FLA)] + CS + IH$$

The first term in C_5 computes the quantities and costs to acquire and maintain new, peculiar items of depot and base shop support equipment (SE) utilized in repair of FLUs. The quantities are derived by considering the anticipated repair workload, the servicing capability of the shops and certain characteristics of the SE.

From queueing theory, we are given

$$\rho = \frac{\lambda}{n\mu} \leq 1 \tag{5.1}$$

where λ is the workload arrival rate, μ is the service rate of one server, n is the number of servers and ρ is the combined utilization rate of the servers which must not be greater than utility. Our objective is to calculate the minimum number of pieces of each item of support equipment ("servers") necessary to support the anticipated workload. Therefore, we must rearrange terms in (5.1):

$$n = \frac{\lambda}{\rho\mu} \tag{5.2}$$

For our purposes, the arrival rate of workload in the base shop for the i^{th} FLU is given by

$$\lambda = \frac{(PFFH)(QPA_i(UF_i)(1\text{-}RIP_i(RTS_i)}{MTBF_1} \tag{5.3}$$

The service rate for one unit of the j^{th} item of SE in support of the i^{th} FLU given by

$$\mu = \frac{(BAA)(1\text{-}DOWN_j)}{(BMH_i) + BCMH_i)} \tag{5.4}$$

And the combined utilization rate, ρ, is given by the variable BUR. Therefore, by combining terms, the quantity

$$\frac{(PFFH)(QPA_i)(UF_i)(1\text{-}RIP_i)(RTS_i)(BMH_i + BCMH_i)}{(MTBF_i)(BUR_j)(BAA)(1\text{-}DOWN_j)} \tag{5.5}$$

represents the fractional requirement for the j^{th} item of SE to support the i^{th} FLU. In order to compute SE costs realistically, integer quantities should be considered. All fractional requirements for SE item j should be accumulated for all FLUs in the weapon system and the result rounded up to a whole number divisible by M to give the total base-level requirement for SE item j.

A similar discussion applies to the computation of depot SE. Using (5.2) again, the depot parameters are

$$\lambda = \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS)_i}{MTBF_i} \qquad (5.6)$$

$$\mu = \frac{(DAA)(1-DOWN_j)}{DMH_i} \qquad (5.7)$$

$$\rho = DUR \qquad (5.8)$$

The fractional requirement for the j^{th} item of SE to support the i^{th} FLU is represented by

$$\frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DMH_i)}{(MTBF_i)(DUR_j)(DAA)(1-DOWN_j)} \qquad (5.9)$$

which should be integerized to give the depot-level requirement for SE item j.

The second term in C_5 is cost to acquire and maintain items of peculiar SE which are not directly workload-related and items of common SE which must be procured in additional quantities. The arbitrary value of 0.1 is the analog of COB or COD used in the first term.

C_6 = Cost of Personnel Training

$$= \frac{[1 + (PIUP-1)(TRB)]TCB}{(PIUP)(PMB)} \left[\sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} \left\{ PAMH_i + (RIP_i)(IMH_i) \right.\right.$$

$$\left. + (1-RIP_i)\ [RMH_i + BCMH_i + (RTS_i)(BMH_i)] \right\} + \frac{TFFH}{SMI}(SMH)$$

$$\left. + \boxed{\frac{(TFFH)(EPA)}{CMRI}(ERMH)} \right]$$

$$+ \frac{[1 + (PIUP-1)(TRD)]\ TCD}{(PIUP)(PMD)} \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} (1-RIP_i)(NRTS_i)(DMH_i)$$

$$+ TE$$

The first and second terms in C_6 are the costs to train maintenance personnel for bases and the depot respectively. Using the second term to simplify the explanation, the quantity

$$\frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DMH_i)}{MTBF_i} \tag{6.1}$$

gives the total depot labor manhour requirement for the i^{th} over the life of the system. Dividing (6.1) by the quantity

$$(PIUP)(PMD) \tag{6.2}$$

gives the workload-related personnel equivalents required at the depot to support the i^{th} FLU. Multiplying by the quantity

$$1 + (PIUP-1)(TRD) \tag{6.3}$$

reflects the turnover of personnel and essentially gives the total training requirement over the life of the system which is then multiplied by the cost to train one man, TCD. A similar exercise applies to the computation of base-level training requirements in the first term. Note that the last quantity within the first term is applicable only when dealing with a propulsion system.

C_7 = Cost of Management and Technical Data

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} [MRO + (1-RIP_i)(MRF + SR + TR)] \ BLR$$

$$+ \frac{TFFH}{SMI} [MRO + 0.1(SR + TR)] \ BLR \quad + \quad RD(JJ + H)$$

The first term in C_7 is the maintenance labor cost associated with equipment failures to complete the on- and off-equipment maintenance forms, supply transaction records and transportation forms. The second term is the similar cost associated with scheduled or periodic maintenance. The third term is the cost to acquire Technical Orders, overhaul manuals, and other special technical documentation or repair instructions.

C_8 = Cost of Facilities

$= FD + (M)(FB)$

This equation gives the cost of new, special base and depot real facilities (including utilities) necessary for operation and maintenance of the system.

C_9 = Cost of Fuel Consumption

$= (TFFH)(EPA)(FR)(FC)$

This equation gives the life cycle fuel cost for those weapon systems having propulsion systems.

C_{10} = Cost of Spare Engines

= [(LS)(X) + Y] EUC

In C_{10}, X is the number of whole spare engines required to fill the base-level portion of the engine pipeline including both the base repair cycle and the Automatic Resupply and Buildup Time. Y is the number of engines required to fill the depot overhaul cycle. Both X and Y include a safety level stock to protect against pipeline shortages due to abnormal or unpredictable demand conditions. The computation of X considers the mean demand rate,

$$\frac{(PFFH)(EPA)}{(LS)(CMRI)} \tag{10.1}$$

the weighted base pipeline time,

$$(ERTS)(BP) + (1-ERTS)(ARBUT) \tag{10.2}$$

and CONF, the established confidence level factor expressed in terms of off-the-shelf availability. The product of the demand rate and the weighted pipeline time gives the argument (ARGB) of the following equation. The desired value of X is the minimum value such that

$$\sum_{n=0}^{X} \frac{(e^{-ARGB})(ARGB)^n}{n!} \geq CONF \tag{10.3}$$

A similar computation applied for Y where the mean demand rate is

$$\frac{(PFFH)(EPA)}{CMRI} \tag{10.4}$$

and the weighted pipeline time is

$$(1-ERTS)(DP) \tag{10.5}$$

The product of these two terms gives the argument (ARGD) of the following equation. The desired value of Y is the minimum value such that

$$\sum_{n=0}^{Y} \frac{(e^{-ARGD})(ARGD)^n}{n!} \geq CONF \tag{10.6}$$

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BIOGRAPHICAL SKETCH OF THE AUTHORS

Captain George H. Davidson is a native of Memphis, Tennessee. After graduation from secondary school, Captain Davidson enlisted in the Air Force where he served in transportation, job scheduling, and budget at Eglin AFB, Florida, and Ellsworth AFB, South Dakota. After departing the Air Force in 1966, Captain Davidson was employed as an accounting clerk with Swift and Company. During this period, he pursued studies in Business Administration at Memphis State University, Memphis, Tennessee. Captain Davidson returned to the active Air Force in 1968 and performed duty in accounting and finance at Blytheville AFB, Arkansas. In 1970, Captain Davidson was selected for a commission under Operation Bootstrap. He completed requirements for a Bachelor of Science Degree in Law Enforcement at the University of Nebraska at Omaha. After graduation from OTS in October 1970, Captain Davidson served as an Air Traffic Control Officer at McGuire AFB, New Jersey and Osan AB, Korea; as a Major Command Briefing Officer with the Air Force Communications Service; as an Aid-de-Camp to Major General Robert E. Sadler; and as the Chief, Airspace Management Instructional Systems at Tyndall AFB, Florida. He is a member of Sigma Iota Epsilon Honorary Fraternity of the National Academy of Management and Delta Iota Epsilon Honorary Fraternity for the decision sciences. Following his graduation from the AFIT School of Systems and

Logistics, Captain Davidson will be assigned as the Project Copper Impact Monitor at Headquarters Air Force Systems Command, Andrews AFB, Maryland.

Captain Raymond E. Griffiths is a native of Dresden, Ohio where he received his secondary education. He earned a Bachelor of Business Administration degree from Ohio University, Athens, Ohio, in 1969. Commissioned a Second Lieutenant through Officers Training School in 1970, he subsequently was assigned and completed Undergraduate Pilot Training. As a pilot, Captain Griffiths has flown C-130 Airborne Command and Control Center missions while assigned to Udorn Royal Thai Air Force Base, Thailand (PACAF) from 1971 to 1972, and tactical, nuclear, and special operations missions while assigned to the 317th Tactical Airlift Wing, Pope AFB, North Carolina. His experience includes duty as a Squadron Aircraft Commander, Instructor Pilot, and both Squadron and Wing Standardization Evaluation Flight Examiner. He is a member of the National Contract Management Association and Sigma Iota Epsilon Honorary Fraternity of the National Academy of Management. Following his graduation from AFIT School of Systems and Logistics, Captain Griffiths will be assigned to Research and Development Procurement, Aeronautical Systems Division, Wright-Patterson AFB, Ohio.